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SUSTAINABLE PRODUCTION OF QUALITY BRONZE ALLOY BEARINGS IN UNDER-RESOURCED SMALL SCALE CASTING FACILITIES

Chozi Vincent Lungu

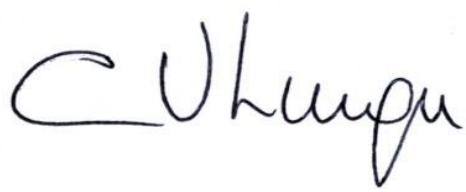
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A thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy

Johannesburg, 2020

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted to the Degree of Doctor of Philosophy to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.



(Signature of Candidate)

12th day of **October** **2020**

(Day) (Month) (Year)

ABSTRACT

There are good reasons to keep the local economy of the Copper belt in Zambia growing. Mining consumables and spares that can be manufactured locally such as bronze sleeve bearings is one way of doing so and can benefit local people a great deal. Bronze sleeve bearings of a fit for purpose quality can to a large extent be cast in a small under-resourced foundry (SURF) sustainably. Sustainability implies survival requiring both consistency of output and cost effective selection and use of secondary materials and aiming for products suited to the market. There is therefore a combination of both technical and economic or business questions. The research examined challenges encountered in a typical SURF and sought to offer a solution for cost effectively producing near net size finished bronze sleeve bearings of a composition that achieves the required mechanical properties to replace directly machined varieties. It was aimed therefore to produce fit for purpose sleeve bearing that represented value for money and were cost effective. Within this thesis focus was on one selected candidate bronze foundry, Fox Foundry, situated in Kitwe on the Copper belt of Zambia.

To establish the fit for purpose standard, the methodology employed sampling of used bronze bearings considered successful in service from producers and various users. These were tested for chemical, mechanical and metallurgical properties. Experimental castings were made using a permanent mould at Heroes Foundry and the University of Johannesburg. Factors examined for the experimental castings were; temperature, composition, feeding, pouring and mass. A matrix design approach was also employed to optimise on the number of experimental runs required as opposed to using conventional factorial method. The resulting microstructure from each experimental cast was the response variable determined.

Test results of the bronze bearings considered successful in service (or OEM) showed irregular microstructure, inconsistent mechanical properties and unacceptable porosity levels. Chemical composition results indicated no control on levels of alloying elements and that had an impact on microstructure and properties dependent on it. Results from experimental castings on the other hand showed that a consistent and optimal microstructure was key in producing a successful bearing as it was the basis of all secondary properties. It can be concluded that a SURF such as Fox Foundry of Kitwe can successfully produce near net sleeve bearing requiring little or no machining providing basic elements of quality in materials and processes are adhered to during production. Whilst SURFs have a low fixed capital base the costs of energy use and metal procurement are an important contributor to competitiveness and should be monitored carefully.. A training programme developed for a typical SURF which when implemented can complement the important measures of material and process quality control and energy conservation to ensure a first time casting fit for purpose.

The work undertaken in here is dedicated to enterprises and individuals serving in the foundry sector particularly in Zambia contributing tirelessly to improving local economic conditions where they are based.

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LIST OF ACRONYMS AND SYMBOLS

ASTM	American Society for Testing and Materials
DBZ	Development Bank of Zambia
FOLC	Foundry low temperature casting
HV	Vickers hardness
KCM	Konkola Copper Mines
LHTC	Laboratory high temperature casting
LLTC	Laboratory low temperature casting
LMTC	Laboratory medium temperature casting
LSMFEZ	Lusaka South Multi Facility Economic Zone
MCM	Mopani Copper Mines
MCTS	Metal Casting and Technology Station
NFM	Non-Ferrous Metalworks (Z) Ltd.
OEM	Original Equipment Manufacturer sample
SAE	Society of Automotive Engineers
SHS	Standard hydraulic stock
SMS	Standard mining stockLabH
SPS	Standard processing stock
SURF	Small under resourced foundry
UNS	Universal Numbering System
WFO	World Foundry Organisation
ZCCM	Zambia Consolidated Consolidated Copper Mines
α	Alpha solid solution matrix phase
β	Beta second phase
γ	Gamma second phase
δ	Delta second phase
ε	Epsilon second phase
η	Coefficient of friction in Stribeck equation
μ	Ordinary coefficient of friction

CHAPTER ONE

1. Introduction and background

Zambia is a landlocked southern African country. The 2013 GDP per capita was USD 3, 810 (cf in the same year 2013 and in USD; Zimbabwe 1, 690, Mozambique 1, 100 and South Africa at 7, 313 in 2012). The twin major challenges are to grow the economy and employment. The two are interdependent but not mutually exclusive. The unemployment rate averaged 14.4% between 1986 and 2014. The 2019 rate was 13.2% (Government of Zambia Central Statistical Office figures). One route to economic growth and employment is through value addition to primary copper. Currently almost all primary copper production is exported without any form of beneficiation with only less than 1% of mine production retained locally for added value purposes.

1.1 Statement of the problem

Zambia is a major producer of copper derived from ores on the Copper belt. Most of the ore is open cast mined on the copper belt in north western Zambia using heavy earth moving equipment. Some of the important wear parts on these types of equipment are bronze bearings, the subject of this study. The equipment and wear parts are imported mainly from South Africa. The delays associated with importation represents an opportunity cost. As bronze is an alloy of copper, the opportunity arises for locally manufactured value added products. However the perceived risk of ineffective bearings from small scale producers by major users such as mining companies may inhibit developmet of this market until these perceptions are ameliorated. With adequate training and experience, fit for purpose quality bronze sleeve bearings can be cast in small scale under-resourced foundries in a sustainable way.

1.2 Objectives of the study

The main objective of the study therefore was to;

(i) Determine the factors and conditions that would lead to the production of quality bronze bearings in repeated short runs in a small scale under-resourced foundry using bearing bronze C93200 alloy

(ii) Examine that reliable short run production of commercial quality bearings is sustainably achievable in small scale under-resourced foundries in Zambia at a cost that represents value for money.

(iii) Work within the composition of the standard alloy C93200 considered closest to that commonly used in ordinary bearing applications and used as a guide compositon only for the purpose of preparing feedstock for laboratory casting.

1.3 Justification for the study

1.3.1 Solution sought

The research sought to offer a solution for cost effectively producing near net size finished bronze sleeve bearings of a composition that achieves the required mechanical properties to replace directly machined varieties. That however must be achieved in a sustainable way for the business concerned taking into account that lack of suitable technology is not the only challenge facing such businesses. Other than availability of technology, there are many other facets of the business to consider such as access to suitable hardener alloys and testing facilities for compositional and quality control purposes. Fit for purpose quality directly cast sleeve bearings are more cost effective than the machined varieties from standard bar stock from a material use point of view.

Whilst direct casting of sleeve bearings would involve less machining than in the traditional case the interplay between the cost of moulds and the cost of machining had to be considered to achieve substantial production cost savings alongside timely delivery.

As indicated above sleeve or journal bearings are traditionally produced from blank materials that are cast as solid or cored cylinders and mass produced in highly automated foundries by centrifugal, chill, continuous and sand casting techniques. The choice of alloy type and composition or grade depends on the desired application and is itself dictated by loading and other operational conditions. A number of approaches in the past prior to the commencement of this work in 2013 have attempted to offer solutions on the issue of value added metal manufacturing in general. There has been no work known to have looked at the problems associated with quality of locally available bronze alloys specifically and how the sector can produce sustainably and grow.

1.3.2 Support to the local economy

The timely availability of essential spares through local production is crucial to the sustainability of the local economy. There is also potential for industrial spin offs. As an example and at the time of undertaking this study, Zambia experienced long lead times and high costs in supply of industrial spares sourced outside the country, giving a low order fulfilment situation. The opportunity cost of delay is significant. However confidence in under resourced local foundries was perceived to be low. The ability of a small under-resourced foundry (SURF) to produce quality replacement bronze bearings required the improvement of appropriate scrap selection, management and

transformation of the cast microstructure. That would more likely involve a change from the coarse elongated to a fine equiaxed grain structure of the casting. A full understanding of the factors responsible for high quality production in a small foundry environment would greatly help in improvement of castings at that level and compete with traditional producers in an innovative way.

1.4 Research outline

1.4.1 Working hypothesis

The working hypothesis adopted was that *reliable short run production of commercial (fit for purpose) quality bearings is sustainably achievable in small under resourced foundries in Zambia (at a cost that represents value for money).* The hypothesis included four (4) elements;

(i) **Technical.** What is a fit for purpose bearing in terms of performance and properties? Can one produce an adequately performing bearing from scrap materials and what are the steps involved? What skills are required and how does one transfer the knowledge and skills to under-resourced rural foundrymen?

(ii) **Teaching or training modules**. Educational and foundry specific skills. This applies within the context of a sustainable business and Government of Zambia facilitation of a suitable business environment.

(iii) **Sustainable business**. What is required of a business in terms of the following; market, product, skills and money? How does one develop a sustainable

business? What does “value for money” represent? Cash flow issues include borrowing capacity and security of materials at the place of work. At what price can a jobbing foundry compete and how can that be achieved cost effectively? What does a typical OEM bearing cost per kg as delivered on site (to include logistics and taxes)?

(iv) **The role of Government**. This is its role in general and in developing and maintaining a suitable climate. What is currently obtaining and what is required? What has been successful in similar economies?

Unless the above or more is done, the business or company producing the bearings will not be sustainable. A number of steps outlined in 1.4 were taken in order to test the hypothesis and that included compilation of data from experimental castings undertaken in a laboratory.

1.5 Remainder of thesis outline, contribution of study and summary

Following the introductory chapter are the literature review, experimental design and results sections in that order. The rest of the chapters include discussion of results, conclusions made and recommendations. The last part consists of appendices of results, illustrations and graphics of processes and operations encountered during the course of the study. The study conclusion notes that whilst fit for purpose castings can be reliably achieved in small under resourced foundries the proviso is that the employees are adequately trained and given the opportunity to gain experience.

The study was limited to non ferrous foundries using bronze scrap as feedstock and not any other foundries. Other than two trial castings undertaken at Heroes Foundry in Lusaka, the full range of experimental castings could not be performed at any of the small foundries for various logistical reasons. Laboratory castings at the University of Johannesburg in that regard came in handy. The study highlighted the challenges faced by SURFs in various ways and central in addressing that is provision of knowledge and skills training suggested in Appendix 5 as a direct contribution. Other contributions are seminar and conference participations indicated in Appendix 15.

The underlying assumptions to achieve successful production of fit for purpose sleeve bearings include adequate cash flow for the business and a reliable uptake market for the products. Others are sustained security for materials used at the foundry and low cost training provision that is supported and subsidised by government agencies. The study noted limitations in access to materials (in terms of type, size and variety) for testing at all facilities visted as well as vital information on operations.

CHAPTER TWO

2. Literature Review

Introduction

To address the hypothesis that *reliable short run production of commercial quality bearings is sustainably achievable in small under resourced foundries (SURFs) in Zambia at a cost that represents value for money*, the literature review for the study focussed but was not limited to four (4) main areas noted as follows;

(i) Casting fit for purpose quality sleeve bearings under rudimentary foundry conditions

(ii) Attributes or characteristics perceived to be of value to small businesses

(iii) Methodology development for casting bronze sleeve bearings using expert models

(iv) Review of competing production techniques

2.1 Casting fit for purpose quality sleeve bearings under rudimentary foundry conditions

2.1.1 Capital intensive large scale versus small under resourced production

Note that capital intensive is not necessarily a function of scale. Large scale producers tend towards continuous production of a relatively small number of products cost effectively. Repetition is lauded. Change is slow and versatility restricted. Small scale producers on the other hand tend to be jobbers, producng a wide range of products and providing variability. Change to meet expectation in the small scale sector is expected.

As such small scale producers choose capital investment products that enable versatility such as a six axis machine where as a large scale producer may use a one or two axis machine to do one thing only. Part of the contribution from this work has been provision of a working guide for sleeve bearing production at a small scale under resourced mini as distinct from micro foundries.

2.1.2 Helpful casting techniques

The final properties of a cast bearing depends to a large extent on orientation during casting, on its section thickness and composition. The foregoing was confirmed by Shinde *et al* (2013) in their work on ductile iron castings. Campbell (2012) in his paper "Stop pouring, start casting" emphasized the aspect of employing counter gravity feeding mechanisms when making castings as the technique eliminated the presence of bifilms in the metal delivered to the mould under laminar conditions. Bifilms were known to be the single biggest source of casting defects that included porosity and cracks.

In many casting alloys bifilms act as nucleation sites for intermetallic compounds that may be present in a melt and to a large extent dictate the morphology of the intermetallics (according to Campbell's account). Other than counter gravity casting, techniques that may be applicable at the small foundry level include a well designed gating system, casting yield control and filtration of molten metal prior to casting. Dispinar *et al* (2004) emphasized in their paper "Critical assessment of reduced pressure test – Porosity phenomena" that achievement of reliable and repeatable properties of castings much depended on use of improved and better metallurgical control

techniques. In this account the reduced pressure test (RPT) was applied to study the extent of porosity in castings formed as a result of interaction of bifilms with the melt.

Dispinar *et al* further explained that although porosity (thermal shrinkage , hot tearing or gas voids) in many types of castings is known to be responsible for majority of failures, it is less understood in terms of how it arises. In particular, the occurrence and contribution of bifilms to formation of porosity in melt systems is not appreciated. A bifilm in the presence of hydrogen gas enables the latter to diffuse and expand within it and lead to pore formation without any difficulty. The term porosity is used extensively in the commercial casting industry to describe a variety of cast defect situations. However it is the morphology of the porosity in terms of size and shape among others that helps to identify a specific type, its origin, frequency of occurrence and possible impact on cast properties

Proper identification of type of porosity, location in a casting and other attributes by a skilful user can greatly improve product quality once such information is relayed to a producer. Such action cuts down on re-works and improves working relationships between supplier and end user. Handling of hot metal at elevated temperatures leads to several reactions with gases and other non-metallic substances, physical changes in the metal stream all contributing to porosity formation. Blowholes and pinholes are large and tiny gas related porosities respectively whose occurrence in castings is specific. Shrinkage porosity and that due to hot tears are other examples and either may contribute to the other's formation. Solid inclusions resulting from oxidation or presence of unwanted substances or dirt are also common defects in castings.

2.1.3 Key bearing alloying elements required

Pure metals on their own have little or no use structurally and can also present difficulties in shaping or casting as in this case. Copper is combined a variety of elements that impart specific properties for chosen applications. In the case of bearing bronze, the elements and why they are added are tin (strengthener), lead (machinability) and nickel (strengthener). The Universal Numbering System (UNS) assigns codes of C80000 to C99999 for cast copper alloys and identifies three distinct categories that are based on solidification (or freezing) range. The solification ranges for the groups are; 50 ^{o}C (I), 50 – 110 ^{o}C (II) and over 110 ^{o}C (III). Pure copper, chromium copper and special bronzes such as aluminium, manganese and nickel belong to group I.

2.1.4 Group II copper alloys

The intermediate or group II alloys have beryllium coppers, silicon brasses and bronzes and copper-nickel alloys. Silicon brasses and bronzes in group II melt easily and pour or cast quite well due to their excellent fluidity. They are however susceptible to hydrogen pick up when over heated and care should be taken to prevent that. Copper-nickel alloys of the same group tend to have less fluidity due to the significant presence of nickel especially when it is in excess of 10% in composition and inevitably require higher treatment temperatures than silicon brasses or bronzes and risk excessive hydrogen pick up.

2.1.5 Group III copper alloys

These alloys have the widest solidification range of the commercial copper alloys commonly in use and these are; leaded red brasses, leaded tin-bronzes and high leaded

tin-bronzes. The alloys used in this research belong to this group. The long solidification range property of these alloys makes them susceptible to dispersed porosity if cooling of the metal is not handled well during casting. A combination of the use of chills and feeders to extend feeding distances and have favourable directional solidification is important during the casting of these alloys. It is recommended that during casting of these alloys, special temperature sensors for moulds be used to ensure that the right temperature is attained in the mould before pouring. This is especially true for moulds where premature freezing may lead to incomplete filling of the moulds.

The best treatment atmosphere for these alloys is one that is slightly oxidising. When ready for casting, the metal must then be de-oxidised using phosphor copper at a controlled rate and just allow a sufficient remnant amount of oxygen for metal fluidity. At the same time, care must taken to avoid contamination of melt with phosphorus from the deoxidiser as that leads to porosity formation. It is worth pointing out that at every stage of the production process such as material charging, melting, fluxing and degassing, melt holding and transportation within the shop there are external factors that directly influence or impact product quality.

These factors may be furnace maintenance, weather conditions, chemicals used and so on. Additionally legislation and environmental management certification applicable may also influence the quality of castings. Unlu and Atik (2010) noted that the high thermal and electrical conductivity of copper as well as its corrosion, self-lubrication and wear characteristics especially when alloyed with tin made it suitable for use as a bearing material more than any other alloy combination. Other possible bearing materials for sliding friction applications are those based on zinc, aluminium, brass,

babbit (white) metals (antimony, tin, lead, cadmium, bismuth and zinc) and a host of non metallics including plastics.

Unlu and Atik further pointed out that bearing properties of low coefficient of friction, high heat conductivity and good corrosion as well as wear resistance were paramount in addition to high load bearing capacity. The two researchers' work was centered around measurement of operating bearing parameters such as coefficient of friction, temperature and wear loss in relation to the load-velocity (PV) factor for various combination of materials based on bronze, brass, copper, zinc and a low manganese medium carbon steel. Lead substitution in bearing materials by bismuth for example had environmental benefits while still maintaining the quality of the sleeve bearings. Although lead was an important element in bearing bronzes for its contribution to supporting higher operating loads than would be possible without it, Thompson *et al* (2010) reported successful performance tests of lead free bronze bearings.

2.1.6 Wear as an essential bearing characteristic

An investigation of sleeve bearing wear characteristics were evaluated in a high lead babbit metal by Upadhyaya *et al* (1997). Microstructural changes were observed in the babbit composition when spray formed during formation as opposed to conventional casting. The spray formed material was more dense and had a better microstructure than the conventionally cast type. That was attributed to controlled or rapid cooling. The resulting microstructure had direct beneficial effects on wear and other mechanical properties due to a reformed grain structure. Therefore improved microstructural control in combination with fine equiaxed grains can be used to produce sleeve bearings in a SURF by improving production control.

Yuanyuan *et al* (1996) showed that microstructural control of aluminium bronze (KK) by adding special elements during casting resulted in improved wear properties. The volume ratio of soft alpha (α) to the hard beta (β) in the aluminium bronze matrix was found to be two-thirds. The above study indicated that aluminium tended to segregate to the alloy surface and formed an oxide layer which in turn increased adhesive wear. Yuanyuan *et al* further noted that there was no clear correlation between a bearing's mechanical properties and its coefficient of friction. The paper concluded that elimination of porosity in the bearing casting greatly improved fatigue and wear resistance.

Equey *et al* (2011) agreed with Yuanyuan *et al* that there existed no clear correlation between mechanical properties of a bearing and friction and wear properties. This study also observed that formation of an oxidized layer on bearing surface was the mechanism by which lead in the alloy contributed to improved wear resistance. It was further elaborated in the work that a bearing's microstructure as well as its surface roughness impacted on the oxide layer formation. In supporting the above researchers, Prasad (2004) had earlier observed that microstructural features (or phases) of bronze bearings had a far greater impact on the wear response property than mechanical properties had. Prasad elaborated that even with optimum composition and microstructure, bearing operating parameters such as load, thermal stability and lubricating tendencies were influenced by positive effects of the phases present in a bearing and not necessarily its microstructure.

Prasad *et al* (1996) also in an earlier study elaborated on the role of microstructural features or phases in promoting lower wear rates in bearings. That was in work based

on zinc-aluminium alloy (ZA27) bearings in comparison with conventional bronze ones. It was found that the ZA27 alloy out-performed a common bronze bearing under a variety of testing conditions. The ZA27's only short coming was that it could not be used beyond operating temperatures of 120 degree Celsius. The relevance of the reported significant difference between ZA27 and conventional bronzes needs to be understood more in the context specific operating conditions. Prasad and co-workers noted that in conventional bronzes, the intermetallic compound, Cu31Sn8, once settled in inter-dendritic regions of the alloy matrix provided the required load bearing capacity.

The equivalent and responsible microstructural phase in the case of ZA27 alloy was CuZn4. In this work, reference was also made to the existence of 'Transfer Layers' on surfaces exposed to wear. Secondary alloying phenomena occurred in transfer layers giving rise to new phases in the metal structure that were in turn responsible for new and beneficial properties of the bearing alloy. Occurrence of severe and unexpected wear in bearings can adversely influence the performance of the product.

Wear rate on a bearing can be measured by determination of mass loss or through the measurement of energy dissipation (Aghdam *et al*). Wear rate can also be calculated using mass loss and the duration of the test. The energy approach in friction analysis combines the key wear parameters of speed, normal force into a single entity. Frictional property changes in a material have been known to influence temperature rise and the latter can therefore be used to monitor performance of the bearing. The authors also suggested that it was immaterial if the journal bearing operated as boundary or mixed mode lubrication. It is important during the friction tests that a minimum amount of

time be allowed for stabilisation in order to determine the mean value for the coefficient as would be typified in a Stribeck curve. Note also that from the work of Aghdam *et al*, a model can be used to study temperature distribution in a bearing during the time it is in operation.

The versatility of copper based materials for friction applications is further supported by Kucukomeroglu *et al.* Investigation into friction behaviour of the materials retains a lot of interest however due to limited understanding of the same. The authors acknowledge that copper and other base metals in their pure form possessed lower wear rates in comparison to their alloy forms such as CuSn10. In addition the authors state that there was evidence to show that tribological properties of bearing materials could drastically alter when subjected to environments other than the normal atmosphere. In the study by Kucukomeroglu *et al* on the bearing material CuZn39Pb3, it was found that the friction coefficient of the material increased as the test atmosphere tended towards a vacuum. The reverse was true of the friction coefficient when the test atmosphere was increased towards the normal atmosphere.

Kovalchenko *et al* agreed that the widespread use of copper based alloys for bearing applications is due to the alloys' moderate to high heat conductivity properties that make it possible to dissipate heat away from contacting or sliding surfaces during operation. Therefore a clear correlation between friction properties and the test atmosphere for the bearing materials existed from the data obtained by the authors. Miyoshi in supporting the foregoing explained that a vacuum environment necessitates greater atomic adhesion of the constituent elements or contacting asperities in an alloy leading to higher coefficient of friction values. Ordinary atmospheric or air conditions

with moderate to high relative humidity (RH) on the other hand encourage presence of oxide films and other contaminants which impact to reduce the friction of a material in contrast to when the same material is tested under vacuum.

Rudrakshi and Pandey and their respective co-authors add that under reduced atmosphere conditions, lead in the alloys spreads easily to the contacting surfaces thereby reducing friction due to its low shear strength as well as low elastic modulus and hardness. Under reduced atmospheres, the role of lead as a lubricating agent is further enhanced by the presence of frictional heating that makes the alloy material viscoplastic. According to Miyoshi, the adhesive layer of the contacting asperities in the alloy is more severe under vacuum conditions than in the case of the normal or air atmosphere. It is also stated that the reaction potential of an element in an alloy has an effect on the formation of the transfer layer. The level of transfer layer formation is responsible increased or reduced friction properties. Sadykov and co-workers studied friction behaviour in copper and brass materials and noted that wear behaviour was dependent on key structural parameters such as grain size, phase composition and texture.

Sadykov also made reference to the work of Kucukomeroglu *et al* suggesting that adhesive wear was the dominant mechanism exhibited by CuZn39Pb3 in the dry friction environment. Reduction of pressure or creation of near vacuum conditions during sliding contact led to severe plastic deformation and formation of a fine grain structure in the surface layers. With high temperatures in the surface layers as a result of contacting friction, the lubrication function of lead in CuZn39Pb3 greatly improved. During boundary lubrication, the friction behaviour of brass is characterised by

superplastic deformation as a result of intergranular sliding of α-phase grains as well as growth and coalescence of pores, formation and propagation of cracks and development of wear particles. A full understanding of working bearing load is important in choosing materials for bearing design and that is key. The load is normally taken to depend on the projected area of the mating components. This can lead to wrong estimation of the PV factor or indeed the rate of wear of the contact surfaces. It is known that the real area of contact is actually a small part of what is assumed to be the apparent area (Archard 1953).

2.1.7 Bearing lubrication modes during operation

There are three distinct modes in which a sleeve bearing assembly can operate and these are; boundary, mixed film and full hydro-dynamic. The combination of coefficient of friction, η, surface velocity, V and operating load, P yields a hydrodynamic variable denoted as $\eta(\frac{V}{P})$ whose increasing value leads to greater hydrodynamicity (refer to the Stribeck curve in Fig.2.1.7a).

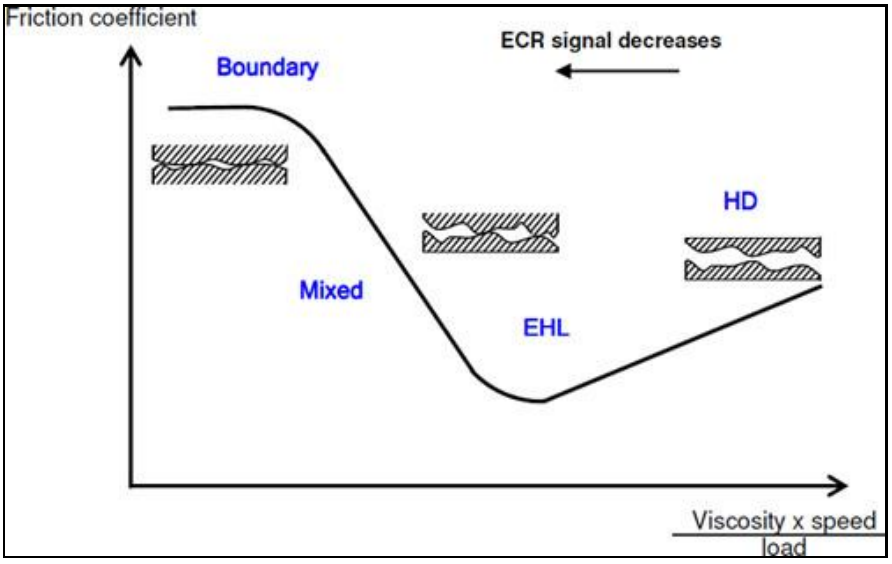


Figure 2.1.7a: Stribeck curve for lubricated sliding surfaces (CDA, 1997)

In the plot of friction versus the ratio of surface velocity and load, ($\frac{V}{P}$), in Fig.2.1.7a, the indicated terms represent the following;

ECR = Electron cyclotron resonance (a process for depositing coatings on substrates)

EHL = Early hydrodynamic lubrication

HD = Hydrodynamic lubrication

2.2 Attributes or characteristics perceived to be of value to small businesses

2.2.1 Role of small businesses and the cost advantage

Small scale businesses made up the majority of the industrial sectors of many countries and contributed a great deal to employment and wealth generation (Shonesy and Gulbro, 2004). While key success factors for survival and sustenance remained generic, there were inherent differences between regions and countries of the World that ultimately spelt out long term success. Goods or services offered needed to be suited to a given market and offered at a price perceived by that market to represent value for money. There is a distinction between the cost of production and the value perception of a given market. Generally price is not a function of cost. Whilst it is true that the selling price of goods sold must exceed the cost of production if the company is to survive, the perceived value put by the market of an individual product may be less than the cost of production - it may also be far greater .

2.2.2 Key success factors for small businesses

Wadhwa (2012) reviewed the factors that governed an entity's ability to adapt to the changing environment in the light of competition and other issues in his publication

"Flexible manufacturability and handling automation in metalcasting SMEs". Although the author focused on technological automation in discussing flexibility and adaptability in manufacturing, Wadhwa noted that the issue of cost was more critical to the survival of a metalcasting SME than it was to that of a traditional Original Equipment Manufacturer (OEM).

Kader *et al* (2009) in their paper "Success factors for small rural entrepreneurs under the One District One Industry programme in Malaysia" analysed a number of internal and external factors. The authors found out that the role played by government in promoting small business success impacted more significantly in the case of Malaysia than the other factors studied. Kader *et al* specifically showed that while internal factors such as good business planning and skills were important for rural entrepreneurs, the overriding requirement for rural business success among all others was government support in a number of areas such as infrastructure improvement, training and market access.

2.2.3 Importance of linkages with OEM groups

Ivarsson and Alvstam (2004) studied linkages between small scale producers of industrial components and large corporate bodies. "International technology transfer through local business linkages: The case of Volvo trucks and their domestic suppliers in India" showed that it was possible to attain high level skills and technology transfer for producing high quality industrial goods such as sleeve bearings. The attainment of a "local supplier" status in a linkage relationship with an Original Equipment Manufacturer (OEM) was highlighted. The authors noted that due to a high level of cooperation between the manufacturer and local suppliers, the technology transfer

process also included technology diffusion that represented a transfer of understanding. In the Zambian context and with reference to bronze bearing production, a possible way to achieve integration is through a tolling production arrangement within major consumer's premises. That would assure financial and material security as these are the major issues faced by small scale metal producers.

2.2.4 Effect of business size and ownership

Wijewardena and Tibbits (1999) considered firm and industry specific factors in evaluating small business success. Small firms were generally described as family owned or operated and employing a dozen or so persons and in some cases the number of employees could be many more. The widely raised issues of personality attributes of owner-managers and their impact on the success of the businesses they operated was not ignored. The two authors' conclusions appeared to have favoured firm size as a decisive factor in business survival. They suggested that smaller firms were more dynamic in their operations than their larger counterparts. That dynamism allowed for better transformation planning unlike in the case of larger businesses. The model used by Wijewardena and Tibbits was based on determining growth of the sampled firms in Australia.

2.2.5 Business and social environment review for Zambia

Introduction

Governments are elected by the electorate to implement a given policy framework. Implementation requires resources including money. Part is raised through taxes on corporations, business and individuals, these improved by growing the economy as a

whole. Within this, some sources are quicker and more certain to realise taxes, base metals such as copper in the Zambian case, than is the manufacturing arena, a longer term strategy. On the other hand the main purpose of business is survival. Consequently the longer term social investment must be government driven with a view of longer term benefit at the expense of short term returns. The government of Zambia through various policy instruments that Micro, Small and Medium Enterprises (MSMEs) are a sustainable way of providing livelihoods through wealth and employment creation. It is a universally held view that the contribution of the MSMEs sector to a country's economy is significant (Zambia Manufacturing Sector Survey report, 2011). The report noted that the MSMEs are an effective vehicle for equitable distribution of wealth and is a source of affordable goods and services for the majority of the lower income population.

Data from the survey report showed that the MSME sector in Zambia was significantly dominant in nearly all the economic sub-sectors with the Fabricated Metal Products and Basic Metal Products categories that include foundries contributing 2.1% and 0.40% respectively to the gross national income during the year 2010 (p81). At the higher end in terms of MSMEs dominance were the Food, Beverages and Tobacco and Wood and Wood Products categories contributing 71% and 9.1% respectively to gross national income in the same year. Zambia's national development planning processes highlight the significance of the involvement of the MSMEs in delivering wealth through documents such as the Sixth National Development Plan (SNDP), Commercial, Trade and Industry (CTI) and the Agricultural policies. It is said that ordinary Foreign Direct Investment (FDI) inflows as a macro-economic measure often have a weaker side on direct employment creation than initiatives that are developed locally. FDI generally

concentrates on capital intensive development near market outlets as this is less complicated to manage. The case of Zambia in the last ten (10) years in particular showed moderate and consistent growth rates averaging 6% per year most of which was attributed to FDIs but the impact on job creation was minimal especially in the marginal areas of the country where poverty was more widespread. The Citizens Economic Empowerment Commission (CEEC) through the Citizens Economic Act no. 9 of 2006 is a direct outcome of the CTI policy. The objective of the CTI policy is to increase citizens' participation in the national economy using specific support and empowerment actions or activities. The strategies outlined in the CTI policy were actualised through a CTI policy implementation plan document that ran from 2010 to 2014 (MCTI, August 2010). A CTI policy implementation plan review document is expected following the completion of the first phase.

Major findings of the MSS report and implications on policy

Casting is a base industry. Success of the foundry sub-sector in Zambia hinges on the performance of the manufacturing sector as a whole. The MSS report of 2012 in its assessment of the sector made reference to trends in the following five (5) key areas during the period 2006 to 2010; Production and Sales, Value Added, Government Revenue, Net Profits and Employment and Income. Although production and sales grew an average 9% during the period under review, growth of the value added component declined and was recorded to be a paltry 3.3% and was well below the intended target of 7%. The MSS report suggested that there was severe erosion in value added contribution during the period due to poor performance of the closely related sub-sectors namely Base Metal Products and the Fabricated Metal Products. It was

suggested in the report that due to a drop in base metal prices, several mines on the Copper belt closed. As a result demand for inputs in their operations equally declined.

On the other hand, increased cost of production was experienced by other sub-sectors such as those in agro and wood processing resulted in reduced value added figures reported. All ten provinces of Zambia have a significant share of agro-processing industries though wood and wood products were dominant in Western and North-Western Provinces only. The urban provinces of Lusaka, Central and the Copper belt were more diversified with presence of chemical and chemical product, base metal, fabricated metal product and as well as non-metallic mineral product industries. The said industries in these provinces were also of medium to high technology nature in comparison with those present in the rural provinces.

Macro-economic environment

The issues highlighted under this heading help to contextualise sustainability issues facing small enterprises. Survival of the enterprises will depend on how well they can employ the coping strategies that they elect to use. Bartering and tolling are some of the ways in which many small enterprises and communities have sought relief over the inability of the formal economy to overcome disadvantages. It was felt by manufactures in the field that the macro-economic environment was not supportive of a vibrant manufacturing sector as a result of high inflation and unfavourable exchange rates. The costs of manufacturing inputs as well as that of imported finished goods made local products in many cases uncompetitive. It is commonly felt that many imported items are highly subsidised (for example by China) to below local production cost levels by countries of origin. This makes locally produced items uncompetitive and undesirable.

International trade policy framework

Although not extensive and fully actualised, regional and continental trading blocs such as the Southern African Development Community (SADC), Common Market for Eastern and Southern Africa (COMESA), Most Favoured Nations, African Growth and Opportunity Act (AGOA) and the Economic Partnership Agreement (EPA) provide some protocols for trade. The MSS report showed that the above instruments and others were largely responsible for growth in the Zambian manufacturing sector and its export drive into countries such as United States, Canada, Japan and China.

Ironically, essential imports and finished goods into Zambia were subject to unfavourable tariff measures that were not supportive of growth in the manufacturing sector. Suppliers to Zambia were subsidised just as foreign owned companies based in Zambia enjoyed tax free inputs (usually from associate companies) disadvantaging their local Zambian competitors where that applied. Non-tariff measures on the other hand such as stringent quality standards based on several criteria were a hindrance to Zambia's export drive.

Domestic trade policy

Foreign suppliers captured more than 80% of the domestic market for manufactured goods during 2010 reportedly worth US$3.6 billion according to the MSS report. The paltry share of domestic producers was, it was believed, due to trade diversion practices among other reasons. In this case, successful exports to countries such as D R Congo, welcome as it may be, often were at the expense of developing or accessing the domestic market in the first place. The report also highlighted that the Proudly Zambian

campaign did not resonate as well among consumers in Zambia as a similar thing did in South Africa.

FDI versus local entrepreneurial capacity

The MSS report identified that Zambia lacked the critical entrepreneurial capacity it needs as a middle income country (p116). The MSS report cites a figure for entrepreneurial density of 10 registered enterprises per 1,000 inhabitants as minimum for a middle income status (Zambia instead has 5). It is also on record that during the MSS study period, more than 70% of exporting firms in Zambia were foreign owned and developed from foreign direct investments.

Local competition, fair trade, public procurement and market information

The policy and law on Competition and Consumer Protection in Zambia requires that no business shall engage in anti-competitive practices. Poor enforcement has allowed undue monopolistic and anti-competition practices in the domestic market affecting many goods and services. The sectors mostly affected are energy, telecommunications, water and some agro products. This state of affairs has devastating and direct impact on growth of the industry and support to the MSME's productive sector. Under the WTO-Least Developed Countries rules, Zambia continued to restrict its public sector market despite a government undertaking that it would partially liberalise it in order to foster enterprise development.

The public sector market worth a reported US$1 billion annually is a viable tool for MSMEs' development through provision of work tenders and that during the 2006 to 2010 period that was not used at all. One concern raised by foundry industry players

and picked up during interviews was the separation of policy from implementation without feed back loop. Although most requisite factors exist for establishment and operation of micro enterprises, intra industry information sharing for the purposes of expansion of local or domestic trade is weak or non-existent at all.

The tax and justice system environments

Over reliance on direct formal taxes at the expense of consumptive and other indirect taxes has had a negative impact on businesses in general. Corporation taxes at 35% of profits for formal businesses and individual incomes has not been sustainable and results into uncompetitive pricing. Zambia has not experienced major reforms in the non-mining arena. The development of a permanent revenue base has been elusive. Enforcement of contracts and settlement of disputes was reportedly taking more than one year to achieve during the period 2006 to 2010. That state of affairs was not supportive of the MSMEs development.

Access to financial and social services

Existing financial services in Zambia are structured in a manner to service large corporate entities. MSMEs located in rural areas are particularly disadvantaged. Although it may be true to assert that financial institutions take most of the blame for the status quo, many of the MSMEs on the other hand have made very little progress at embracing prudent financial management practices, thus limiting their access to working capital. Clearly there is a huge gap in providing long term capital in the country. The risk averse financial sector seems not keen to develop or apply special skills to assess and price the risk of doing business with MSMEs.

Despite the abundance and widespread availability of hydro-power in Zambia, its cost per kWh is noted to be among the highest in the region especially for low load consumers (p120). The electricity tariff structures as at February 2015 tended to favour large industrial consumers on high load supply. Although the coverage of telecommunication services in Zambia is considered satisfactory, the cost of services remains prohibitive and not supportive of business due to the many anti-competition practices among the major service providers. Where mobile services have improved in quality, it has been at the expense of fixed line services in generally all areas of need.

The coverage for water and associated services in Zambia reputed to possess more than 60% of the region's watershed resource is a mere 40% or less of the dwelling places in the country. Where water supply and sanitation coverage has been possible, challenges arise in terms of quality and consistency of supply in addition to affordability. Commercial transport services for delivery of inputs of production and conveyance of finished goods are dominated by road transportation. Rail transportation for industrial goods was generally non-existent at the time of documenting this. This has encouraged escalation of road transport costs country wide.

2.2.6 Leveraging industrialisation using the mining resource

Mining as a driver of industrialisation

The sustainability of bronze bearing production in the Zambian setting is largely premised on the support the sector would receive from the country's mining industry which has expanded massively since the year 2000. In a working paper by Fessehaie *et al* (2016) titled "Can mining promote industrialization?: A comparative analysis of policy frameworks in three southern African countries", the authors look at the policies

and strategies designed by three countries including Zambia to leverage their mining sectors to foster upstream and downstream linkage industries and support upgrading of technological capabilities. The relationship between natural resource endowment and industrialization is always a big subject for debate.

There are skeptical views on the matter as well as those supported by dependency theorists and proponents of the resource curse. In short, factors of technology, skills, knowledge and policies play a key role in the success of resource based industrialization. Fessehaie *et al* contend that the said factors combine to enable expansion of the natural resource sector by improving resource discovery, its extraction, resource processing technologies and processes and has moved many countries into new industries related to their resource sectors. Investment in domestic technological capabilities directly promotes success of resource based industrialization.

Sectoral GDP contributions

World Bank data (2016) shows that sectoral contribution to Zambia's GDP changed drastically between 1990 and 2013. The percent contribution to GDP in the two reference years of 1990 and 2013 for four key sectors are as follows; Mining (15.2% and 25.7%), Manufacturing (36.1% and 8.2%), Agriculture (20.6% and 9.6%) and Services (28.1% and 56.5%). The jump in mining GDP is due to emergence of a new Copper belt in the North Western Province of Zambia as distinct from the old Copper belt. In the same period manufacturing and agricultural GDP contributions drastically reduced suggesting that the scope for improvement remains in the two areas remains extremely high. Cost structures for mineral extraction between the old and new Copper

belt are very different owing to type of resources and technologies employed among other factors.

However, the need for a vibrant manufacturing sector that can support the two regions of mining with possibilities of provision of essential spares made locally is great and will continue to grow. Drastic decline in manufacturing contribution to GDP during the period in question was not only true for the Zambian economy but was equally so in the case of Zimbabwe although underlying factors for the two countries may be very different. Fessehaie *et al* conclude that economic dynamics seen in Zambia and other countries in the region highlight how important it is to promote formal manufacturing activities to create employment and value added. That is where bronze production, the basis of this research, and metal melting and casting in general fit in.

Challenges faced by the manufacturing sector in Zambia

Zambia's manufacturing capabilities in the mining supply chain were eroded during the 1990s with the privatization of mining assets and the introduction of trade and investment liberalization measures according to Fassehaie. Other than for a few exceptions, the country's manufacturing base was effectively replaced by small scale importers. Expensive capital locally means long terms plans for refinancing of production equipment and keeping of large stocks of inputs and spares in order to supply within short lead times presents major challenges. In the year 2014, mining procurements annually were worth nearly US$2 billion of which just under US$100 million represented locally manufactured goods or 5% of total. A huge portion of the lucrative procurement business with mining companies is effectively ring fenced with so called solution providers who act on behalf of their mining clients.

In theory therefore, opportunities for growth of local supply firms are numerous. Apart from financing challenges, the issue of certification of local producers and suppliers is another. Often locally produced goods and services are uncompetitive as a result of not meeting various prescribed standards. In the last few years, an initiative to support local suppliers in many ways including some challenges referred to above has emerged in the form of the so called 'local content initiative'. Zambia Association of Manufacturers (ZAM) in conjunction with the Chamber of Mines are spearheading the Zambia Mining Local Content Initiative (ZMLCI). However lack of a strong government presence and leaving ZMLCI entirely to the goodwill of private players may render the impact of the initiative poor.

The role of skills in industrialisation

Many commentators have suggested that the infusion of Science, Technology, Engineering and Math (STEM) skills alongside industrial development policies is critical to the sustenance of a strong manufacturing base. Zambia has seen a decline of these critical skills since the 1990s mainly because the organisations that supported their development have been abolished alongside with a drastic reduction in financial and material support to tertiary institutions involved in training of such skills. Major mining companies have joined an initiative to support relevant skills development for the sector through the Zambia Mining Skills and Education Trust (ZAMSET) which it is hoped will help to narrow the critical skills gap.

2.2.7 Multi-facility economic zones and general status on financing in Zambia

The government of the Republic of Zambia through a newly created structure called Industrial Development Corporation (IDC) designated investment zones in three

regions of the country. Multi-Facility Economic Zones (MFEZ) are currently set in the following towns; Kabwe, Kitwe and Lusaka representing the major industrial hubs of the country and with the view of attracting medium to high technology firms for economic growth. During course of research (October 2016), I visited offices of the Lusaka South Multi-Facility Economic Zone (LSMFEZ) Limited in order to appreciate its programme objectives and specifically understand the incentives put in place to support growth of small and medium scale enterprises. The comments indicated below were courtesy of the office of the Managing Director for LSMFEZ.

The LSMFEZ occupies an area of 2,100 hectares and fully serviced by grid electricity, tarred roads, telecommunications, solid waste management as well as water and sewerage services. According to Statutory Instrument no. 47 of 2010, the facility caters for industries such as (i) Gemstones and metal processing, (ii) Electrical and electronic appliances, (iii) Agro processing, (iv) Medical diagnostic services, (v) Scientific and measuring services and (vi) Research and development services among others. Apart from provision of physical utility services by the LSMFEZ, the programmes permits investing firms tax breaks in the form of import duty on capital equipment and income tax on profits for a period of five years from date of set up. Assistance may also be given by the programme in negotiating technology transfer deals where that is desirable.

The Development Bank of Zambia (DBZ), a State Owned Enterprise (SOE), has for sometime operated financial facilities from which various types of businesses have benefited. The success rate and impact of the DBZ financing facility in the last few years was not made clear at the time of compiling this report. Some guidelines on accessing the DBZ facility are attached in **Appendix 13**. Table 2.2.7a is a summary of

the financial access requirements as contained in the guidelines appended. In theory, capital for setting up and operating an SME up to the required amount may be obtained from DBZ subject to availability of funds and the applicant fulfilling the conditions laid out. The applicable annual interest rates to loans as indicated in the table and using December 2016 figures (inflation rate at 9% and interest rate at 16%) can range from 13% to 32% or higher if loan currency is Zambian Kwacha. If the loan is designated in the US Dollar or other international currencies, the applicable rate is the risk adjusted London InterBank Offered Rate (LIBOR) which may or may not be cheaper than the local currency equivalent. The payment of upfront fees totalling 6% in addition to designated interest rates may make borrowing by small firms unaffordable.

General situation on economy and access to financing in Zambia

According to a World Bank report (Zambia Economic Brief, December 2016), the country faced tough global and domestic conditions since mid-2015 resulting in a low Real GDP growth of only 2.9% during 2016 and leaving the per capita income essentially the same. For nearly ten years prior to that GDP growth averaged 7.4%. Some major challenges included tight liquidity, lack of commitment for economic reforms during first half of 2016 and widespread power outages. Government revenues during the period fell below target but there were no corresponding adjustments in expenditures resulting in substantial accumulation of arrears.

Although measures in monetary policy helped bring down inflation and kept exchange rate stability, the measures impacted adversely on the availability of credit and the growth of cash reserves both locally and externally. The cost of capital in Zambia for short or long term purposes is high and currently (January 2017) ranges from 35 to 40%

per annum in the final analysis. This is way above the national rate of inflation going around 8% as at the same date of reference. As at the end of December 2016 and according to Bank of Zambia (BoZ), the weighted lending base rate was 15.5% and the average lending rate was 29.5%. Interest rates paid on ordinary bank deposits during December 2016 ranged from 2.1 to 2.8% per annum.

Table 2.2.7a: Development Bank of Zambia summary of financial access

Description	**Facility**	
	EUROBOND	Other
i) Eligibility	SMEs	SMEs & Larger Companies
ii) Currency	Loans may be obtained in Zambian Kwacha and any other eligible foreign currency such as US Dollars.	
iii) Loan Amount	Min: ZMW 1,000,000 Max: ZMW 5,000,000	Min: ZMW 1,000,000 Max: N/A
	The set limits also applies for equivalent loan amounts requested in foreign currency	
iv) Interest Rate		
- *Zambian Kwacha*	SME Base Rate (Inflation Rate) + 2%	Bank of Zambia (Policy Rate) + Risk Margin%
- *Foreign Currency*	12-Months Foreign Currency LIBOR + Risk Margin%	12-Months Foreign Currency LIBOR + Risk Margin%
v) Grace Period	This will range from a minimum of 3 months to a maximum 24 months on the Principle amount, depending on the cash flow projections. There will be no grace period on Interest, unless in exceptional cases.	
vi) Tenure (Repayment Period)	Not exceeding 7 years (84 Months)	Not exceeding 15 years (180 Months)
vii) Fees		
- *Appraisal Fee (%)*	1% of the loan amount applied for (Non-refundable upfront payment)	
- *Facility Fee (%)*	2% of the loan amount applied for (Payable following facility approval)	
- *Commitment Fee (%)*	3% on undrawn balance after 90 days	

(**Source**: Development Bank of Zambia, December 2016. 1 USD = 10 ZMW)

Call or special deposits on the other hand attracted rates from 2.4 to 12.9% per annum depending on period involved. The government sets the base or policy rate while the lending rate is arrived at by the banks themselves determining the risk associated with an individual applicant and can be as high as 40% as indicated above. A total of six (6) financial institutions operating in Zambia including the central bank were visited during January 2017. These were Barclays Bank, Stanbic Bank, Standard Chartered, Zambia National Commercial Bank, Indo-Zambia Bank, Development Bank of Zambia (DBZ) and Bank of Zambia. The country has a total of nineteen (19) operating commercial banks to include subsidiaries of foreign banks, locally owned private banks and those in which the Government of Zambia co-owned with other foreign governments.

Other than DBZ and the financial policy implementer and regulator, BoZ, the rest of the banks including others not mentioned have a generic set of guidelines for applications to access financing (see sample in Table 2.2.7c) from Stanbic Bank on documentation required for credit assessment). BoZ sets the policy rate as a reference and banks add a margin on the base rate and the resulting total will depend on an individual applicant's risk profile. Banks categorise clients into small and medium scale enterprises (SMEs) and large corporates in terms of their annual sales turnovers with US$2 million being a typical reference point. For SMEs in this case the turnovers would be $2m or less.

As said already above, the cost of capital can be as high as 45% when risk is taken into account while interest earned on deposits of value of K20,000 and above earn a maximum of only 13% per annum. The consolidated information on financial institutions' transactions is reported fortnightly by the central bank (BoZ) in a bulletin

called **Statistics Fortnightly** with all vital information on the local, regional and global economies.

Table 2.2.7b: Commercial banks' interest rates (in ZMW currency)

Period	Avg. lending rate	Interbank rate	Cheque account	Savings	Deposits over K20,000						
					1 day	7 days	14 days	30 days	60 days	90 days	180 days
Dec. 2018	23.56	9.84	1.21	3.00	2.29	3.51	3.30	5.28	6.61	7.58	9.07
Dec. 2019	28.02	12.45	1.59	2.99	2.63	3.40	3.28	6.77	8.41	8.83	10.06
Aug. 2020	25.21	8.45	1.53	2.95	2.70	2.76	3.04	6.09	7.51	8.40	10.08

Source: Bank of Zambia (October 2020)

Individual banks' policies and practices on lending could not be accessed after several attempts and solicitations. The general response from the six banks visited was that the information regarding the policies and practices was confidential and could not be released to third parties.

Availability of liquidity

In theory Zambia's financial markets have sufficient funds to lend to businesses especially the SME sector whose capital requirements are not as demanding as the larger corporate industry. According to the BoZ and during August 2020, total liquidity (or reserve funds) in the Zambian economy was US$580 million accounted for in the local currency equivalent. The amount includes currency in circulation, statutory reserves to include those held in US dollars as well as commercial banks' current account balances. ~~The Development~~ According to the Bank of Zambia direct lending to all sectors during August 2020 for instance was US$3.2 billion. The beneficiary

sectors were the construction, manufacturing, tourism and hospitality, financial services, agriculture, other services and agro processing.

The Government of Zambia remains a significant borrower of both local and foreign funds in the Zambian economy. The instruments through which that happens is the use of treasury bills and government bonds. This has the effect of limiting the amount of capital that would otherwise be readily available for the productive sectors of the economy as well as pushing inflation and the cost of capital upwards. The yield rates for both treasury bills and bonds have steadily increased over the past years and has also attracted the attention of foreign investors. Surplus funds accruing from foreign direct investment (FDI) projects in the country a lot of times are used for purchasing treasury bills and GRZ bonds rather than re-investment in expansion of the same FDI projects from which the money was earned. Total claims on government have grown significantly over the years. This situation can adversely impact the productive sector that needs affordable capital more than the government does.

Perspectives of bearing bronze producers

A visit to Heroes Foundry in Lusaka and a discussion with owner and operator, Herold Banda, was made on 3rd February 2017. Mr. Banda financed the acquisition and subsequent setting up of Heroes Foundry through savings raised from exports of various types of scrap metal. The foundry's major equipment of a cupola and oil fired crucible furnaces and support facilities as seen in Fig.2.2.7a were likewise added through such financial savings. Mr. Banda submitted that it was not possible for him to rely on bank support for purchase of capital equipment as repayable interest on borrowed funds was prohibitive. Heroes Foundry had however utilised from time to time short term

overdraft facilities with their bankers to finance operations and the costs of such repayments ranged from 35 to 40% per annum on borrowed funds.



Figure 2.2.7a: Melting underway at Heroes Foundry

The above state of affairs at Heroes Foundry was not different from that obtaining at Fox Foundry in terms of financing production. Since 2014 Fox Foundry has been in negotiations with the Development Bank of Zambia over a loan to improve and expand production at the company with little progress made. The foregoing position was confirmed by foundry proprietor and operator Mr. Chiti Ching'ambo. Fox Foundry reliance on commercial banks for operating capital and other essential needs is equally limited as was the case at Heroes Foundry referred to earlier.

Perspectives of policy players

The Ministry of Finance indicated on 5th February 2017 that the Government of Zambia was in the process of creating an Entrepreneurial Fund (EF). The initiative will see the cost of capital substantially reduced from the current levels of over 40% per annum as well as act as a guarantor on financing to the private sector especially the small and

medium scale enterprises. The statement (Ministry of Finance press release, 5th February 2017) on the creation of the EF came as a result of wide ranging consultations with various parties locally and outside of Zambia.

The government affirmed its support for the private sector in driving economic growth and the areas particularly targeted were agriculture, aquaculture, value addition, renewable energy and off-grid power generation projects. An important source of financing to support the EF initiative and others alike has been the issuance of national sovereign bonds whose yield rates as of February 2017 have been considered positive at a maximum of 9.01%. The state of affairs has been assisted by a stable exchange rate over a prolonged period, a fall in inflation and good management of other macro-economic fundamentals. The swift return to normal life and business following national elections in August 2016 also helped to stabilize the economy.

Views of independent observers

According to national media reports (February 2017), one Mwansa P Chalwe a financial analyst, observed that although the fundamental determinants of the cost of capital had improved substantially banks and other financial institutions had continued to charge exorbitant rates on borrowed funds. The last twelve months leading to January 2017 have seen a drop in inflation from 22.5% to 6.8%. The central bank, BOZ, on the other hand reduced the statutory cash reserve ratio from 18% to 15.5% while its policy rate also dropped from 15.5% to 14%. In addition investment in treasury bills, a source of substantial funding to government, was impacted on by a reduction in the annual rates from 27% to 21%. Commercial banks on the other hand pay a maximum of 25% on

term deposits on funds mobilized from their customer base giving them a revenue margin of 76% and more.

The figures given above are substantially higher than those obtaining in many regional countries. The cause of the above state of affairs is traced back to the uncapping of the interest rate ceiling by the Bank of Zambia some years ago according to the independent analyst. Part of the solution therefore and according to the same analyst would be to re-introduce legislation that controls interest rate movements rather than leave it entirely to commercial banks to manage on their own. It is thought that with appropriate legislation in place, chances of price fixing and collusion by commercial banks and other private lenders would be eliminated or at best minimized.

A recent initiative on promoting growth of private enterprises

The British Government through UK Aid supported the establishment of a five year initiative called Private Enterprise Partnership Zambia sometime in the year 2016. The initiative targets local small businesses in all sectors with the aim of improving access to quality business development services, facilitating access to finance and by the forging of partnerships between large corporations and potential Zambian suppliers to open up routes to markets. The programme achieves its objectives by implementing four interlinked components and these are;

(i) The Nyamuka Zambia Business Plan Competition

(ii) Establishing Business Linkages

(iii) Offering Business Development Services and

(iv) Provision of Accelerator Funds.

PEPZ recognised that mining expansion was responsible for rapid economic, social and population growth of the large scale mining regions and that there was high demand for everything including high-tech engineering and support yet most of those services and other necessities are imported into the region. This was according to the programme website (www.pepzambia.com) and words of the programme head, James Blewett. PEPZ further noted that there were big opportunities for local firms to meet that supply gap but many of which lacked the management skills and finance to exploit those opportunities. PEPZ helped to create what was currently the only private equity fund in the country in operation and predominantly focuses on Copper belt. The equity fund provides finance to businesses by actively incubating start-up companies and seeks to invest in scalable enterprises that can create jobs.

2.2.8 The local economic outlook and role of central government during 2015 to the present time

Performance of the economy

According to the World Bank (December 2016), the decade preceding 2015 saw real GDP growth in Zambia averaging 7.4%. That slowed down to average 3.0% thereafter in 2015 and 2016 mainly due to tough global challenges and a lack of appetite for economic reform internally. The World Bank further noted that there was weak commitment control and lack of credibility in the implementation of the country's 2016 budget as collection of tax revenues fell below target. There was no corresponding adjustment in government expenditure resulting in a large build-up of arrears. Although a good monetary policy helped check the rate of inflation and kept the local currency

exchange rate with major currencies stable, the measure negatively impacted on the cost of borrowing, the availability of credit and growth of foreign currency reserves.

As energy shortages in the form of electricity persisted during most of the period, there was a slowdown in productivity in all economic sectors. The services and non-mining sectors were mostly impacted by the energy shortages as the two contribute 80% to the country's GDP. The triple shocks during the period were referred to as poor harvest, power shortages and falling copper and other metal prices. The shocks combined to impact the national currency exchange rate downward and push upward domestic prices as well as cause other financial difficulties in the economy. At the end of 2015, the local currency had lost 42% of its exchange rate value and domestic prices risen to 21% when compared with figures of end of 2014.

Zambia's major export earner (accounting for more than two-thirds), copper, lost value on international markets resulting in fall of its price due to slow growth in major consuming nations during the 2015 – 2016 period. The development caused a loss to GDP contribution of 3.5% over the immediate past period and put pressure on the value of the currency, the Kwacha. The stagnation in mining revenues as well as the fall in agricultural output during the period were partly offset by good performance in the services and construction sectors in turn driven by a large increase in public investments of 30% over the previous year of 2014 according to Smith *et al*. (2016). In the case of Zambia and during 2015, there was no doubt that the triple shocks experienced had a direct impact on the macro financial indicators of the exchange rate and inflation levels. Falling commodity prices of metals forced the local currency, Kwacha, to weaken by

up to half its value at the end of 2015 during which time it was trading around ZMW14 to USD1.

Response measures by government and its agencies in managing the economy

In the report by Smith *et al*. (2016), the Government of Zambia and its key agencies responded to the triple shock phenomena in the economy by taking some measures such as tightening liquidity through increased banks' reserve ratios, ruling policy rates, foreign exchange markets and sale of domestic securities among others. These and other measures stabilised the local currency and arrested runaway price increases on many commodities and fuels. One of the biggest casualties from these measures was availability of affordable credit for economic recovery and growth. Although commercial banks themselves were highly capitalised during the period, the level of loan defaults had increased significantly from 5.5% in 2014 to 9% by June 2016.

The report concluded that with the measures taken by government, the end result was that prospects for private sector led growth were significantly diminished while at the same time encouraging publicly funded consumption subsidies. The Government of Zambia would have done well to build on the growth years of 2004 to 2014 by laying down a basis for financial resilience and allowing a broader and more credible diversification of the economy than was obtaining during 2015 to 2016. The heavy reliance by the country on one commodity, copper, led hard currency earnings has the ability to cripple the local currency as well as affect adversely other macro indicators in the economy.

The government was slow or reluctant altogether to engage in implementing policies and programmes that would encourage sustainable growth with affordable credit for the private sector. According to the Porter Diamond model displayed below, the government of Zambia was not articulating sufficiently well on *factor conditions* in its key roles. That was particularly so in the area of ensuring a conducive business or trading environment by way of availability of affordable credit as an example. The regulatory environment has been known to suffer inconsistencies and unpredictability especially with regard to taxation on mineral properties. In addition, start-up and small businesses have experienced unmanageable tax burdens that resulted in closure of operations as was the case with Post Newspapers Limited that was forced into liquidation during 2016.

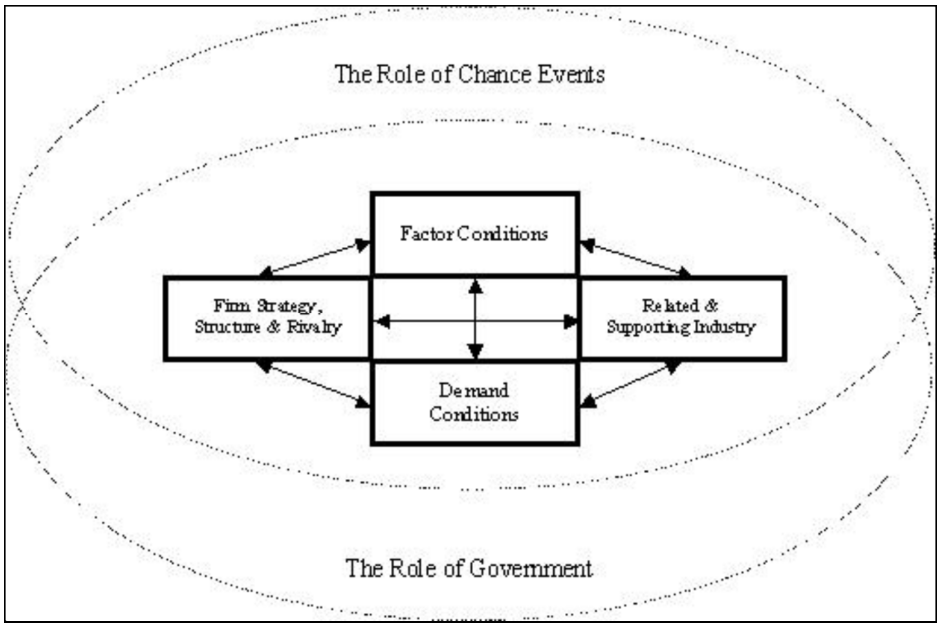


Figure 2.2.8a: Porter Diamond model on role of government

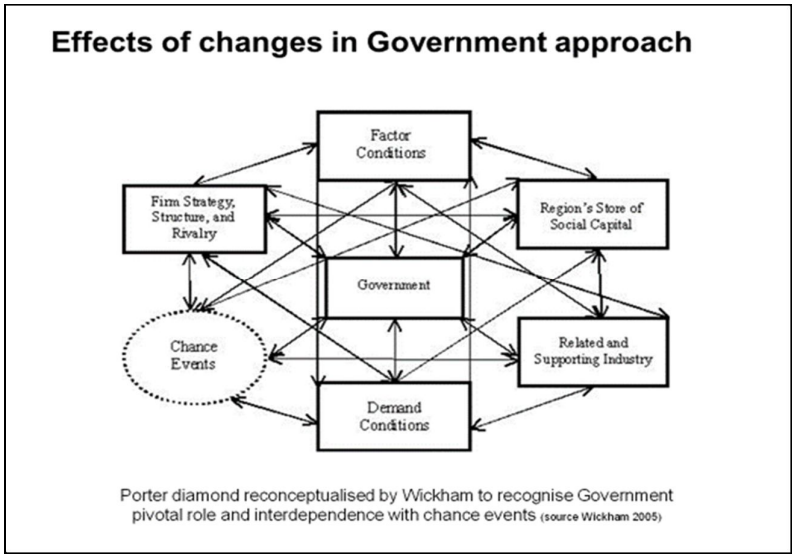


Figure 2.2.8b: Modified Porter Diamond model on role of government

The task that continues to face Zambian policy makers and implementers is moving away from rigid monetary policies and dependence on a single commodity, copper, as a protection mechanism for currency stability. Wickham showed in his research paper (2005) that Australia struggled to move away from its protectionist policies of unsustainable tariffs and subsidies to an environment that was more productive and competitive in both local and international markets. Circumstances surrounding the existence of industry clusters in various parts of the world are not readily transferable noted Boddy (2000).

Simply replicating policies that have worked in successful clusters elsewhere is no guarantee for achieving similar results in a new and different environment. Although infrastructural development is desirable in strategic areas to encourage formation and diffusion of industry clusters, it is not sufficient in itself to ensure cluster formation and development as observed in the work of Feser and Bergman (2000). The two authors suggest that instead cluster linkages and inter industry synergies prove more beneficial

in fostering development in such set-ups. The positive roles that governments can play in support of entrepreneurial activity of industrial clusters include operationalising innovation and training at appropriate levels as well as infrastructural support. One factor that emerges as being key to the growth of Sub Saharan African (SSA) countries' economies is *financial development* according to the Internationa Monetary Fund (IMF) report on regional economic outlook for SSA of April 2016.

Financial development has facilitated the successful implementation of other policies within a country's planning framework to support growth and thereby bring about economic stability. The IMF review report made reference to a statistical benchmark value of the financial development index for the SSA region and many countries were performing well below that. The report further said that raising the countries' median financial development index to its benchmark value would boost their growth by a significant one and a half percentage points. It was also stated that the increase in such growth was not without macro-financial risks to which the countries were to be vigilant. Zambia's financial development index in the IMF survey was recorded as 0.15 while that of South Africa in the same category of resource intensive countries was 0.70 during 2015.

There is ample evidence to suggest that financial development especially at lower levels promotes economic growth according to Sahay *et al*. (2015). There is a threshold beyond which financial development raises volatility in economic growth prospects. Financial development helps improve firms' and households' access to borrowing and promotes greater economic diversification and management of business risk as noted by Acemoglu and Zilibotti (1997).

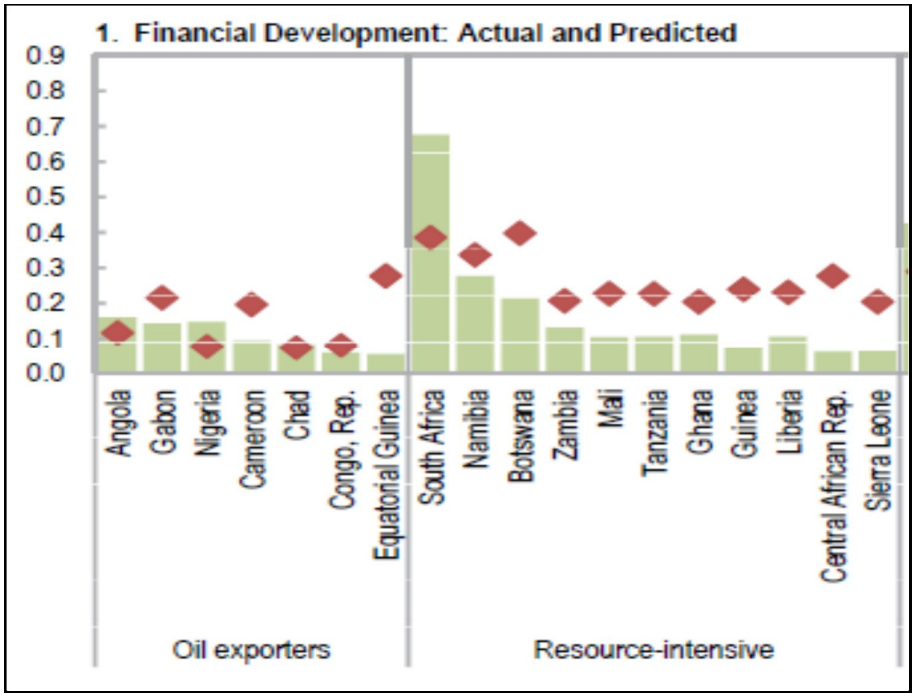


Figure 2.2.8c: Financial development indices (After Sahay *et al*., 2015)

As alluded to earlier, financial development beyond a certain threshold may accelerate shocks especially in an environment laden with market imperfections observed Bernanke *et al*. (1999). Overall however financial development supports growth in almost all situations although effects may differ from one country to another. In most SSA economies, financial development is mostly associated with the traditional banking sector and little if any occurs in alternative financial markets due to limited competition and lack of appropriate infrastructure. Studies in some selected SSA countries including the Economic and Monetary Unit of Central Africa (CEMAC), and the West African Economic and Monetary Union (WAEMU) have shown that eliminating some of the most binding constraints to financial inclusion results in significant impacts on a country's GDP and Total Factor Productivity (TFP) (refer to Fig. 2.2.8d). These constraints include poor enforcement of contracts, demands for high

collaterals and small leverage ratios of the banking sectors according to Dabla-Norris *et al* (2015).

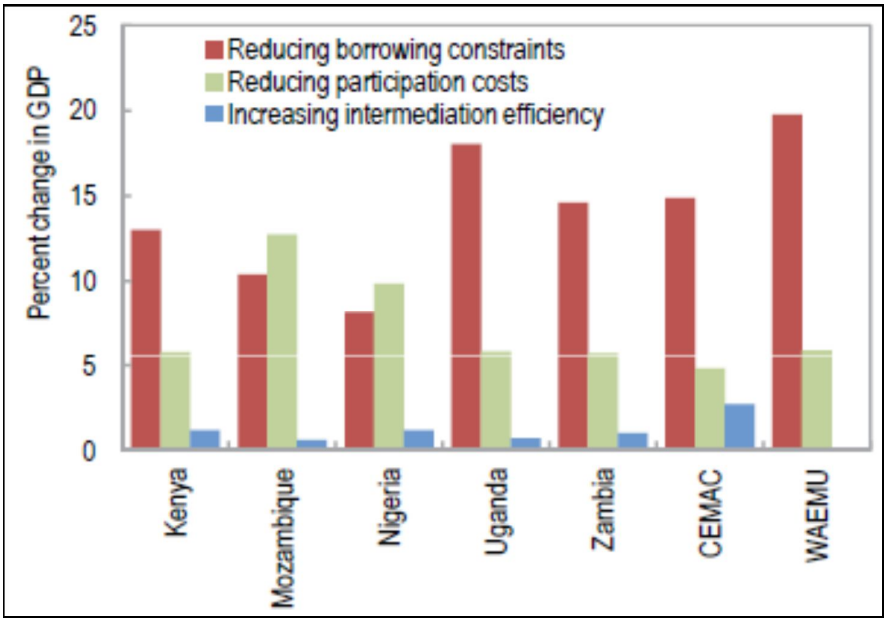


Figure 2.2.8d: Long term impact on GDP of relaxing financial constraints (After Dabla-Norris *et al*)

The above studies further highlight that although the threshold index for financial development is never surpassed by most SSA countries, their protection from shocks that may arise in financial markets remains weak particularly in the light of falling commodity prices upon which many economies are directly dependant. Financial development is promoted by sound macro-economic management while weak institutional quality in the form of legal frameworks and corporate governance take away from it.

Researchers Kose *et al.* (2006) have observed that some elements of globalization such as *financial* and *trade* integration once used in an appropriate manner can positively add to financial development. Keeping inflation in check as well as allowing growth of

real incomes among a country's middle class is good for financial development. It is noted that trade integration overall has a larger impact on financial development than does financial integration at a global level and that is the area where most countries have missed opportunities. Trade integration is assessed in this case in the form of the share of total exports and imports of goods and services in GDP for a country.

On the other hand financial integration may be measured as a share of international assets and liabilities as a share of GDP of the country in question. This is sometimes referred to as the degree of openness of a country's capital account. One factor inihibiting proper financial development through integration in many developing countries is the conduct of financial market participants who tend to demand much higher risk premiums than standard risk ratings that should be generally applicable. Such interest groups and according to Rajan and Zingales (2003) oppose financial development because it erodes their potential rents or profits.

The authors further mention that stronger finance and trade development weakens interest groups' power and can spur financial reform in an economy. That in turn increases chances of attracting high liquidities thereby reducing the cost of capital and consequently foster financial development as emphasised by Svaleryd and Vlachos (2002). Policy measures therefore required to strengthen financial development in SSA countries and according to Gulde *et al*. (2006) include among others providing strong legal and institutional frameworks and promoting sound corporate governance and foster contract enforcement and judicial independence,

2.2.9 Energy usage and efficiency in the foundry sector

Energy situational analysis in Zambia industrial heating options available

The economy of Zambia performed a lot less than was projected and grew just below 3% for the year 2015 and that continued into 2016 according to World Bank reports. The country's largest export earner commodity, copper, experienced low demand from large consumers such as China and that led to depressed prices and earnings. Industrial heating in Zambia may be accomplished by the use of mainly firewood, charcoal, coal, coke, diesel, heavy fuel oils, light petroleum gas, solar photovoltaic (PV) and grid electricity. Other than grid electricity and petroleum products there is no reliable data on the availability and use of other energy forms mentioned above. While petroleum products are widely available throughout the country and generally meeting the required demand, electricity supply continued to face a deficit of up to 1,000 MW at the end of the year 2016.

As at the end of 2015, electricity supply in Zambia was dominated by hydro power (94%) while generation from diesel, heavy fuel oil (HFO) and solar PV accounted for the balance of 6% making a total generation capacity of 2,411 MW. With the commissioning of thermal generation plants at Maamba Collieries towards end of 2016 and further into 2017, the electricity supply pattern will change somewhat and have a total capacity of over 3,000 MW. Electricity tariffs were revised during the course of 2016 in order to migrate to cost reflectivity and encourage more investment in the sector. The power deficit during 2015 and 2016 was mainly due to low generation of electricity from existing plants as stated above.

The national consumption of petroleum products during 2015 was 1,379,781 metric tonnes. Diesel accounted for 59% of total, unleaded petrol was 27% and others such as heavy fuel oils, light petroleum gas, kerosene and Jet-A1 accounted for 14%. Significant amounts of petroleum products are used in the generation of power as referred to earlier. The prices of major petroleum products of diesel and petrol remained fairly competitive in the region whether refined locally from crude or imported as finished products at US$0.79 and US$0.91 respectively. Use of fuel oils with a combination of grid electricity is common with bearing bronze producers in Zambia for melting metal and post casting operations.

Furnace types and vessels in use at Fox Foundry and Heroes Foundry

Both Fox and Heroes foundries utilise oil fired crucible furnaces to melt and treat bronze alloys. Data on consumption of energy at both foundries was however difficult to ascertain fully as accurate logging of usage information was not practiced other than reference to purchase figures only. Additionally the two foundries were unwilling to share specific information on sales of products. Fox Foundry has two 500 kg capacity furnaces while those at Heroes are of the order of 10 kg only for bronze melting purposes. Heroes also uses cupola furnaces for production of cast iron materials. Fox Foundry utilizes only 50% of the energy input to the furnace to melt and treat bronze while the figure at Heroes is 25% based on raw casting output figures. The issue in both cases was where does half the energy input at Fox Foundry and 75% of energy input at Heroes Foundry go?

Follow up visits to both facilities during January and February 2017 showed that while figures for oil used in the furnaces are fairly accurate from records of purchases,

furnaces in both cases are not protected from excessive heat losses escaping with the flue gases. There are also oil losses and contamination of the fuel in the process from storage to furnaces without any means to measure what quantities are actually used for a particular heat or cycle. It was evident at both Heroes and Fox foundries that there was a lack of interest, skills or tools in fully evaluating the actual quantities of fuel used in the melting processes.

Grid electricity at both foundries is used in blowers that inject fuel into burners as well machining and for administrative purposes. Heroes Foundry reported a figure of 3,226 kWh energy units per month while at Fox Foundry that was approximated at 5,500 kWh (based on local currency invoices billed to the respective companies during the year 2016). In both cases personnel at the two companies were unable to apportion the quantities of grid energy used in melting, machining and administrative purposes. Although Heroes Foundry was able to state the quantities of fuel used per tonne of rough bronze castings, total quantities of bearing bronze produced at the foundry in a month or year were not available making it difficult to accurately compare the total energy inputs at the two foundries. Heroes Foundry has a sizeable section that deals in cast iron castings other than the bronze foundry.

Heroes Foundry utilizes 400 litres of used oil to melt and cast a tonne of bronze. This is equivalent to 0.4 m3 of fuel for the purpose. The calculation below shows the amount of used oil as weight equivalent and the cost in the local currency.

0.4 m3 per tonne is (837 kg/m3 x 0.4 m3) or 334.8 kg of used oil.
Energy equivalent is (4.34x107 J/kg x 334.8 kg) or 1.45 x 107 Joules
Energy used at Heroes Foundry is 1.45 x 107 J/kg or 14.5 x 106 J/kg

The above figure is roughly twice what Fox Foundry in Kitwe utilizes



Figure 2.2.9a: A scene prior to casting at Fox Foundry



Figure 2.2.9b: Empty crucible after casting at Heroes Foundry

Analysis of energy input and product output from Fox Foundry processes

Based on 2014 and 2015 figures of 2.05 and 1.95 kWh/kg respectively of rough or total weight of castings (and not final products), the energy used is twice what is theoretical. The furnaces at Fox Foundry in other words operate at 50% efficiency at the most. Heat

losses from the furnaces mainly occurs through the vessel mouths in addition to conduction through furnace walls and at the time of casting or pouring into moulds. Cast products at the foundry come in various forms and yields can range from 70% to 85% according to the foremen in the foundry. Despite the potential for utilizing escaping heat from the melting furnaces to pre-heat incoming fresh charge materials, the foundry has not put any measures to do so. The same scenario obtains at Heroes Foundry. Long serving employees at Fox Foundry however confirmed that the pre-heating furnace charge material was practiced and followed in the years past but has been discontinued for unclear reasons and this has disadvantaged conservation measures.

Energy re-use especially for preheating scrap charge is possible at both Fox and Heroes foundries with a little modification of the charging systems on crucible furnaces. Heroes Foundry would have to think of raising the capacities of their existing furnaces in addition as well. In both cases there are possibilities for continuous or semi-continuous production with improvement in the utilization of energy during melting of metal. Continuous reduction of the unutilized energy at both Fox and Heroes foundries at present remains the most viable way to attain sustainability of the business. That is in addition to securing affordable long term financing for improved melting and casting technologies as well as post casting treatments.

Both Fox and Heroes recycle scrap metal materials as major or only input for melting and producing various finished products thereby making a direct positive contribution to environmental clean-up objectives. Employees at both Fox and Heroes foundries appeared to enjoy personal relationships with owners who were also operators of the

businesses and that contributed to long term loyalty and trust in the two institutions. The owners at both foundries also spoke about regular involvement in community projects the result of which raised their business profiles. There was lack of information from both foundries however on plans put in place for reducing emissions from melting furnaces especially in the light of using used engine oil as main fuel. This was taking away from the positive environmental contributions the businesses were making.

Choices available to foundries in achieving energy savings

Foundries are considered high capital and energy intensity industries. Foundries in Zambia just as those in South Africa operate in an environment that is considered to have low energy costs and high capital costs according to the Aluminium Federation of South Africa (AFSA) 2009 reports. As is the case in many countries energy consumed by industry tends to be priced lower than that offered to the domestic or household market making the case for energy conservation by industries weak and not receiving high priority. Zambia has been experiencing severe energy shortages since 2014. According to an unpublished report by Lungu (2012) on Zambia mineral and energy survey, the total power generation capacity is about 3,600 MW. The known players in the energy sector with the respective generation capacities where applicable are Zambia Electricity Supply Corporation (Zesco; 1,818MW), Copperbelt Energy Corporation (CEC, 80MW GTAs), Lunsemfwa Hydro Power Company (LHPC, 49MW), Zengamina Power Company (ZPC, 0.75MW) and the North Western Energy Corporation (NWEC).

Zesco has in addition a number of diesel fuelled generating plants in seven remote districts around the country with capacitieis of no more than a few hundreds of kilo watts. Since the beginning of the energy crisis in the country in 2014 and according to

a number of uncomfirmed media reports of 2016, the current energy deficit in Zambia is around 1,000 MW. To date there is no known industry wide energy conservation programme that for instance encourages a re-look at equipment such as furnaces used in operations for the foundry industry. The decision environment faced by the foundry industry according to AFSA is controlled mainly by four factors; (i) the market, (ii) capital equipment, (iii) metal prices and (iv) casting technologies and associated process control. Gains as far as energy usage is concerned are likely or realised where operator control or influence can be excercised.

Possibilities for furnace retrofitting lie in many areas such as burner improvement, pre-heating of furnace charge or combustion air using recycled heat from the same system. The theoretical energy required to melt one tonne of bronze assuming no melt, radiative and conductive heat losses is estimated at 181 kWh (see calculation Appendix 11). The actual heat used in practice to achieve the same results and taking into account all possible losses would be of the order of twice the theoretical value or 362 kWh per tonne of bronze (or 1.3×10^9 Joules).

Furnace control technology as a tool for energy savings

As environmental laws in many countries in the world today get stricter than in the years past, the need to implement energy efficiency measures in foundries becomes a major priority. Rische and Doetsch (2013) in their paper titled "Higher economic efficiency in melting through modern induction technology" stated that the efficient use of energy and choice of resources was more important than ever before for the foundry industry. The authors further stated that the greatest improvements in energy use in foundry lay in retrofitting furnace units where savings of up to 50% in energy costs

were realisable in moving from traditional mains frequency induction furnaces to medium frequency varieties for example.

Rische and Doetsch stated that use of improved medium frequency furnaces for melting can increase operational efficiencies to nearly 90%. The authors also identified five major areas as responsible for energy losses on a typical furnace unit as related to; transformer (1.5%), furnace lining (3.0%), power supply (17%), furnace coils (1.5%) and capacitor losses (1%). Only 75% or less of the energy available is therefore used in achieving the melting of the metal. The trend in furnace operation particularly in situations of batch production is in implementing constant power output control units on furanaces. That involves designing the load circuit with a range of 70 to 100% of the rated power output coupled with an automatically adjusting resonance frequency in the same range of 70 to 100%. Operation of a furnace at a steady rated output guarantees smooth operation of the unit and is independent of furnace contents and eliminates the need to leave a heel of molten metal in it before the next recharge cycle. The authors added that steady rated output control provides huge opportunities for energy savings by employing high utilisations at low power peaks as well as simultaneous use of a twin furnace arrangement.

Energy conservation using Materials Flow Cost Accounting (MFCA)

All of the above approaches to energy saving or conservation focus largely on its efficient use. Another approach would be to focus on material efficiency as described in a model tested for the Cleaner Production pilot study in South African foundries. The study was spearheaded by the Environmental Sustainability Solutions (ESS) group led by Seakle Godschalk and Maryna Möhr-Swart. In their work, the authors describe the

use of a tool called Material Flow Cost Accounting (MFCA) in assessing and quantifying the flows and stock of materials in processes and production lines in both physical and monetary terms. The MFCA concept is based on the International Standards Organisation (ISO) framework no. 14051 as indicated in the figure 2.2.9c.

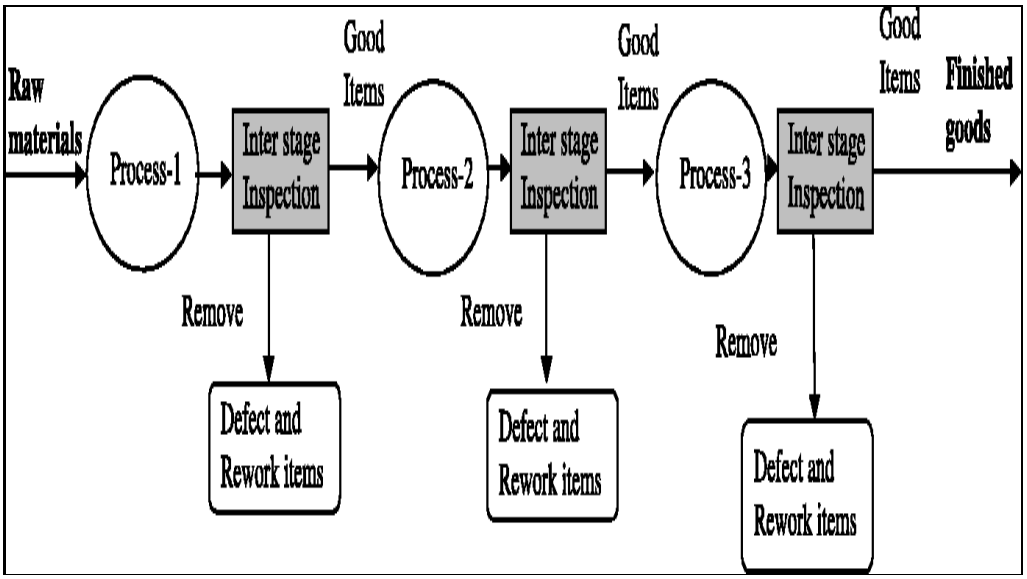


Figure 2.2.9c: Material flow cost accounting – General framework (Goldschalk *et al*.)

Application of the MFCA process offers a more realistic picture of the cost of wastage than does the method of traditional management accounting. Design and inherent process limitations in most foundry operations impact on raw material usage efficiency and in turn on overall resource efficiency to include energy. The ESS group in examining five foundries in South Africa applied what they called a Foundry Materials Loss Model (FMLM) as a variant of the MFCA to determine a number of aspects of material usage efficiency.

Energy efficiency determinations by foundry benchmarking

The German Institute for Foundry Technology (IFG) works with several partners across Europe in a consortia to assess the use of energy resources in foundries. The consortia has eight country partner institutions and ninenteen partner foundries within the European Union (EU). There are also associate partners besides the key ones in bankers, local authorities, foundry associations and participating benchmarking foundries. There also participating associations outside of Europe in China and other countries. IFG has formulated a forty six point list of best practices that identifies key elements and areas in the foundry processes or operations where potential energy savings are possible.

Understanding the foundry energy bill

The process starts with these five key words or phrases; (i) utilities' base charges, (ii) available power demand in kVA (kW), (iii) energy required in kWh (kJ), (iv) fuel and other resource adjustments, (v) utilities' power factor penalties and (vi) utilities' on and off peak rates. This is in accordance with the guidelines offered by furnace equipment manufacturer Inductotherm Corporation of United States (www.inductothermcorp.com). Power supply efficiences of induction furnaces have over the past years improved greatly from the spark gap type of below 50% to one above 90% in the modern solid state version (see Fig.2.2.9d).

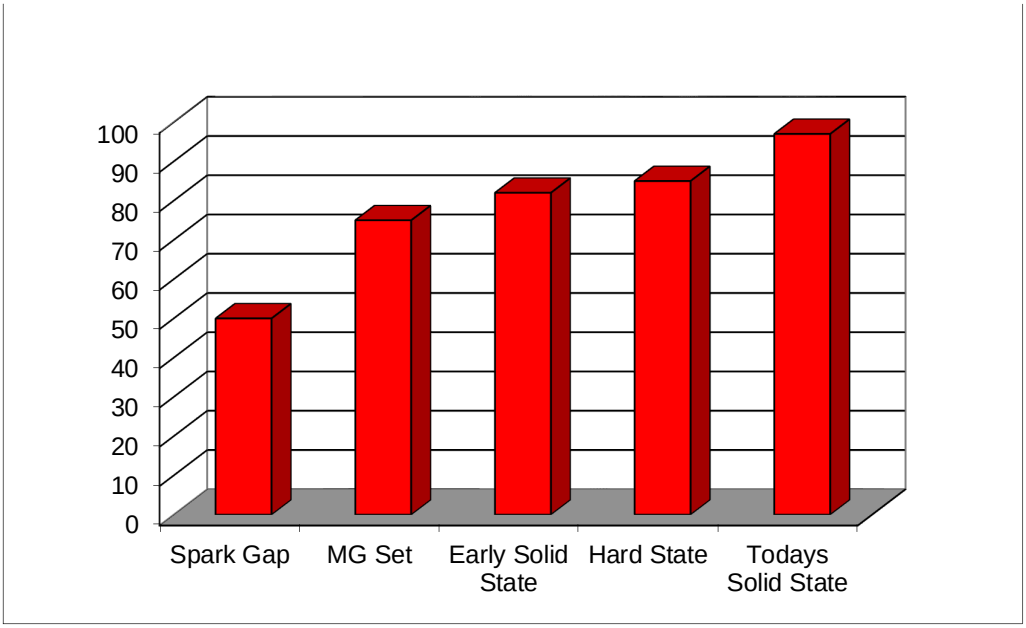


Figure 2.2.9d: Induction power supply efficiency (Inductotherm Corporation)

In deciding power demand levels and frequency of supply (mains, low, medium, high and very high), there are furnace options to consider as well in terms of number and capacity of each unit. Inductotherm cites the following operating parameters; melting rate, equipment utilization, pour rate, power usage, power density and tap size. For a given melting task, various options of power supply, furnace capacity and number are considered. Inductotherm also established that at least 75% of heat is lost from the molten metal surface during operations through radiation loss. Others points of heat loss include refractory bricks, induction coil size, water cooled electrical leads, grid power factor capacitances and through the fume collector.

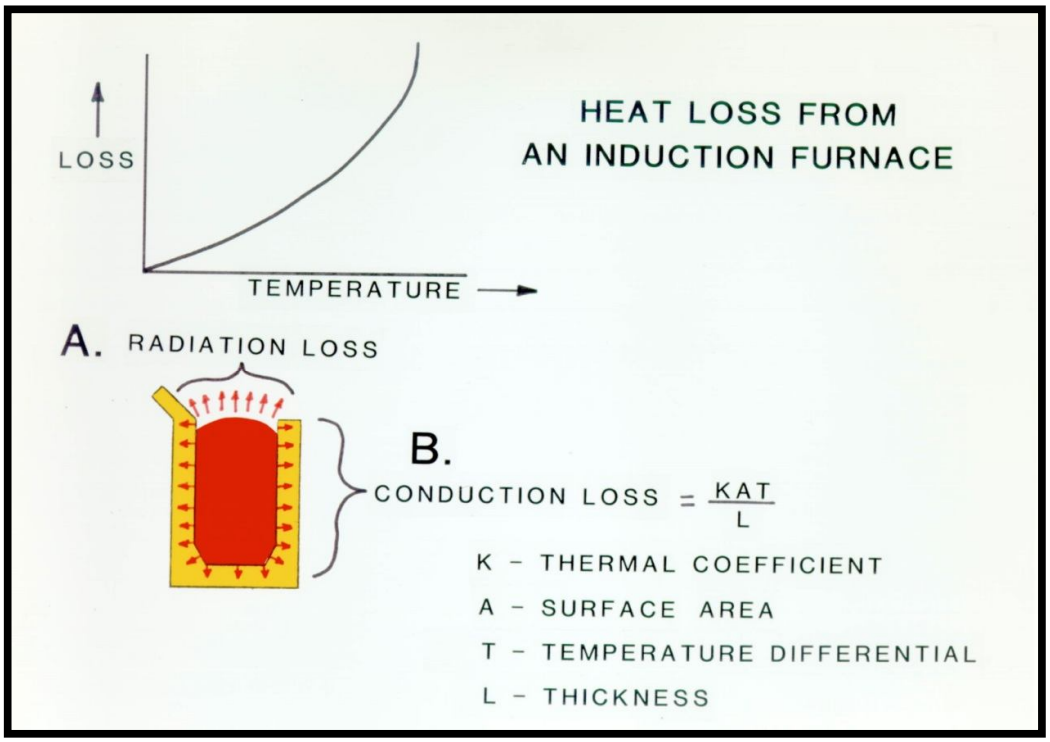


Figure 2.2.9e: Heat loss mechanism in an induction furnace (Inductotherm Corporation)

Real time data monitoring for energy efficiency in foundries

India's Customised Energy Solutions (CES) has studied foundries and other energy intensive industries and explored ways of saving energy in their operations. The layout in Fig. 2.2.9f illustrates the distribution of energy use in a typical foundry. In the process, energy saving opportunities or loads must be clearly identified while taking into account process constraints. In the approach, continuous online monitoring of energy data for all processes is used. Every identified load centre is coded and the information collected using installed systems and evaluated for discussion with plant personnel. Real time output data consists of energy consumption at each load centre as well as the quality of power supplied to the load centre. All measuring instruments or meters are connected to personal computers (PCs) through local area network (LAN) cables and logged through web based communication systems.

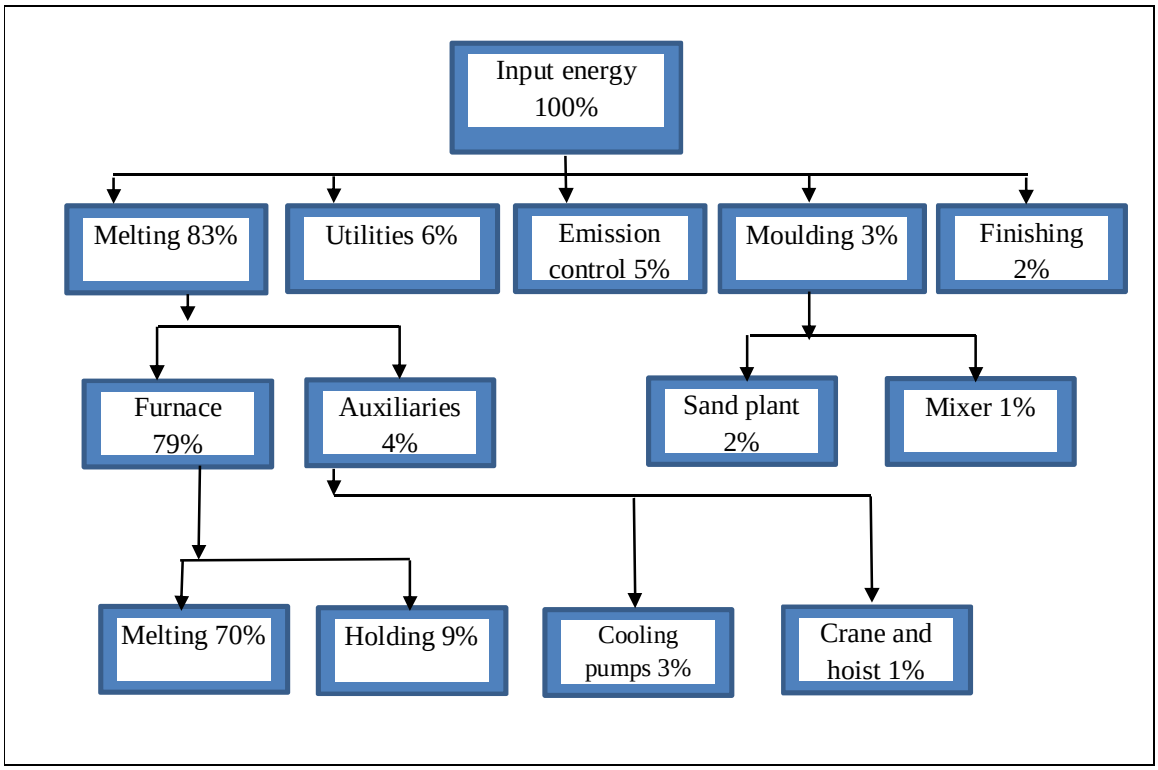


Figure 2.2.9f: Foundry process study with respect to energy use (Customised Energy Solutions)

The reporting system for all above is formatted in order that each production shift can report comparable data. The communication architecture is built in such a way that an enclosed secured network comprising monitored units or load centres which are linked to PCs through a LAN switch and supported with customised encryption. The entire foundry secured network is in turn linked to a main monitoring centre via the internet and can also be accessed by authorised users from anywhere in the World. Typical reporting outputs from each load centre has a time series load curve that shows the following parameters; Maximum demand kVA, Average demand kVA, Optimised demand kVA and Consumption kWh.

From the above captured information, it is possible to benchmark load centre consumption and high energy units such as furnaces are particularly critical. The data

and information collected from above is used in conjunction with discussions with plant engineers and other personnel who have knowledge on equipment constraints. In conclusion and according to CES, the above exercises can be accomplished as follows;

(i) **Without investment** (Change in the work culture and using the best practices). These will pay for the small investment

(ii) **Small and little investments** (Approriate tools and tackles, safe and efficient electrical installations and instrumentation). These will pay for the big investments and

(iii) **Major investments** (Changes in material handling systems, modification in plant layout and energy efficient electric motors). These will enventually pay for themselves and are sustainable.

Lazzarin and Noro (2015) in their paper titled '*Energy efficiency opportunities in the production process of cast iron foundries: An experience in Italy*" used an energy audit study of five iron and steel foundries to present their findings. The key elements of the energy audits were as follows;

(i) Analysis of energy bills in a given period of two (2) years for electricity, natural gas, coke and others

(ii) General information with respect to location, plants' layout with equipment's technical characteristics in models and hours of operation

(iii) Determination of energy consumed by all equipment units by calculation (power data, operating hours and work load factors) and where possible actual measurements during operation and

(iv) Determination of key production indicators such as *gross* and *net* metal outputs related to energy use.

The study by Lazzarin and Noro classified the foundries audited in the study with respect to net castings production per year as large (45,000 tonnes or more), medium (20,000 to 25,000 tonnes) and small (2,500 tonnes). Energy balances were presented for each foundry studied. The information contained energy use per foundry department (furnaces, laboratories, mould making etc.) and the type of utilization (thermal, photo voltaic (PV) or electricity) as well as where (lighting, compressed air etc.). Yearly energy data (consumption of electrical energy and natural gas and electrical energy production from the PV plant) and their respect costs are presented.

Muthuraman (2014) investigated waste heat recovery options in a foundry using heat given off during solidification in sand moulds. The author carried out experiments in which raw material charge to furnaces was placed in moulds adjacent to cavities were molten metal would be poured during casting. The heat distribution in such situations would not be expected to be linear and is governed by the general conservation of energy equation using the Fourier derivations as below and may also be represented as spherical or orthogonal curvilinear equations;

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) + g \quad \text{..... 2.2.9(i)}$$

(In rectangular coordinates)

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(kr \frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \emptyset}\left(k \frac{\partial T}{\partial \emptyset}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) + g \quad \text{..... 2.2.9(ii)}$$

(In cylindrical coordinates)

Where ρ is the material density and C_p is its heat capacity. T and t are dimensions of temperature and time respectively.

Muthuraman in a number of instances and for the experiments conducted recorded heat energy recoveries of between 12% and 22%. If a combination of methods are used other than just placing charge materials in furnace moulds, higher recoveries than reported above were possible according to the author. Ozawa *et al* (2002) examined energy use and carbon dioxide emissions in Mexican industries from 1970 to 1996 from the perspective of the iron and steel sector. The iron and steel industry in Mexico was considered as most energy intensive in comparison with others in the country and therefore a good candidate for energy efficiency evaluations.

The authors used the methodology of energy consumption decomposition analysis based on an Average Parametric Divisia (AVE-PDM) index and a Physical Production Index (PPI). Total energy consumption of the industry is a function of the production volume (or activity), the process and product mix (structure) and the energy efficiency of the production process. In the case of Mexico, the period under study showed that there had been a substantial increment in steel production countrywide. That would have resulted in a proportionately major increase in energy use had it not been for improved energy use efficiency during the same period. The authors highlighted that the main factor that drove down production costs was energy efficiency supported by substantial improvements in furnace technologies by shutting down open hearth furnaces for basic oxygen processes. Other measures adopted for improved were improved process control and automation of major equipment as well as preventive maintenance.

Price *et al* (2002) in their study of Energy use and carbon dioxide emissions from steel production in China noted that data on energy consumption in the country mostly included activities not directly associated with the production of steel. China's steel production in 1996 was just over 100 million tonnes making it the World's largest at the time. The study of energy use in primary industries in China such as in iron and steel making was important due to the potentials for energy savings possible. Although the authors discuss in some detail the various stages of steel making in China from primary to secondary steel production, casting of large ingots and thin slabs, as well as rolling, the focus of the study was on application of methodologies and results therefrom of separating reported Chinese production data into values for actual steel production. Accurate figures on energy use in primary industries are important if meaningful comparisons between countries must be made.

That also allows guidelines provided on energy efficiencies in industries arising from the United Nations Framework Convention on Climate Change (UNFCCC). The study concluded that if best practice technologies had been used to produce the same amounts and types of steel in China during 1995 potential energy savings and reduction of CO_2 emissions would have been 45% in each case. Worrell *et al* (2001) presented results of their study on energy saving opportunities in the United States in their paper titled "Energy efficiency and carbon dioxide emissions reduction opportunities in the US iron and steel sector". The authors reviewed overall industry trends at the aggregate level using guidelines contained in Standard Industrial Classifications (SIC) 331 and 332 with subsidiary guidelines in SIC 3312, 3313 and 3321. The analysis started with a detailed assessment of energy use on the process level to establish the energy balance of the US iron and steel industry.

The assessment also attempted to quantify "non-energy benefits such as increase in productivity or decrease in production costs. Ultimately the potentials for energy efficiency or savings and reductions in CO_2 emissions are interpreted using an *energy conservation supply curve*.

The authors used a three step methodology as follows;

(i) Firstly establish a baseline for material and energy use using national statistical data readily available from the immediate previous year

(ii) Analysis and characterisation of energy efficient technologies to improve energy efficiency and determine the potential application and impact of the measures and

(iii) Assess the cost effectiveness of the potential for energy efficiency improvement using the energy conservation supply curve.

The last step in above methodology is the critical one. An energy supply curve is a means of ranking energy conservation investments alongside investments in energy supply in order to assess the least cost approach to meeting energy service needs. The curve ranks energy efficiency measures by their "***cost of conserved energy***" (CCE) that accounts for both the costs of implementing and maintaining a particular technology or measure and the energy savings associated with that option over its lifetime. The CCE of an option is worked out as shown below;

$$CCE = \frac{Annualised\ Investment + Annual\ Change\ in\ Operating\ and\ Maintenance\ Costs}{Annual\ Energy\ Savings}$$

The annualized investment is determined as follows;

$$Annualised\ Investment = Capital\ Cost * \frac{d}{(1-(1+d)^{-n})}$$

Where d is the discount rate and n is the lifetime of the conservation measure.

2.2.10 Training and diffusion of skills for foundry personnel

The foundry industry in Zambia has existed side by side with the development and growth of the mining sector which started in the late ninenteenth century. Although under developed, the foundry sector continues to play an important role in the provision of essential spares for the mining industry and other sectors. Juganan and Paterson (2012) highlighted in their paper presentation to the World Foundry Congress in Mexico titled "The career path framework (CPF) for the foundry industry in South Africa – an innovative skills development initiative for the training of foundrymen" a number of issues related to skills development. That was in reference to the South African situation. The following were key in addressing the training needs of the foundry sector;

(i) Review of existing foundry qualifications to reflect required competencies
(ii) Development of a career framework from above using an agreed pathway
(iii) Development of an occupational profile for the foundry sector as a result and finally
(iv) Registration of proposed qualifications with the relevant government body.

It has been increasingly recognised that for the foundry sector to grow and fully develop, skills and competencies of personnel in the sector must service other national development goals other than the traditional mining industry. Retraining and infusion of information technology skills in the production processes would greatly contribute to that. Juganan and Paterson recognise that to actualise the process, there are three important pillars to play their roles; government, business community and trade unions.

Government has the critical roles of regulation, stewardship to enable economic growth and balancing between regulation and provision of opportunities to the satisfaction and welfare of the general population. Training and retraining for skills has its support in the quest for a knowledge economy one that is beyond mere value addition to basic commodity materials. Addition of science based graduates and engineers as well as promotion of internationally acclaimed research output and higher degrees contribute to a successful manufacturing and knowledge economy. The foundry industry in Zambia is one such sector that can drive both the manufacturing and knowledge economies. Over the years training of relevant industry personnel has changed from what was referred to as mentorship based to something more generic.

The training and skills needs of the foundry sector in South Africa lay in understanding the processes involved in carrying out work and levels of innovation required in a typical foundry. Central and at the core of those tasks was involment of the artisan. Juganan and Paterson describe an artisan of a trade as an occupation where a qualified person applies a high level of practical skills supported and reinforced by underpinning and applied knowledge to several core requirements of that particular trade. In supporting the career path framework (CPF) development for any trade, an analysis of the local innovation system is considered as complementary. The innovation system model considered by the authors makes a number of assumptions and these are as follows;

(i) Innovation is the main driver of prosperity in a society and that most of it will happen in firms.

(ii) Innovation behaviour of firms is determined by framework conditions such as competition in the market place and a country's economic policies and

(iii) Innovation is sustained by firms working closely with specialised technology and training instititutions that support life long learning.

The structure of the innovation system may be summed up as a structure of four independent pillars consisting of firms, framework conditions, technology institutions and education institutions. Each pillar members have specific objectives and mandates to carry out and operate independently but cooperate in an inter-dependent way.

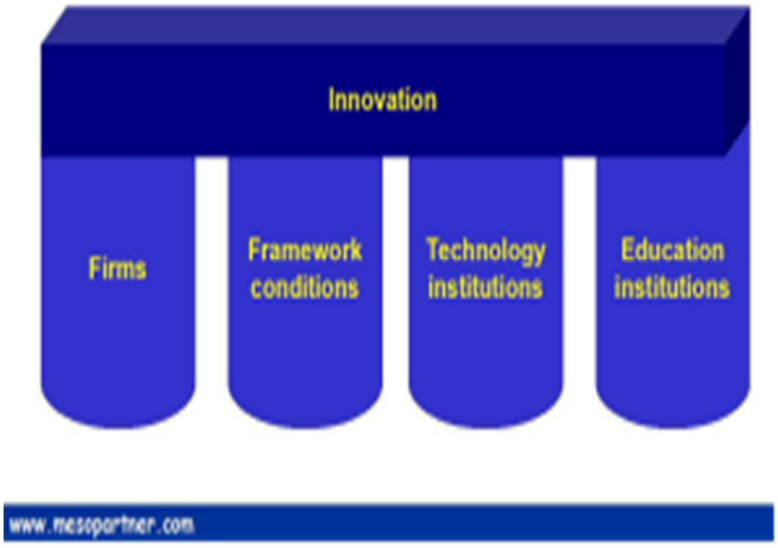


Figure 2.2.10a: The innovation framework model (Juganan and Paterson)

Fig.2.2.10a can be elaborated upon by describing the specific objectives and mandates of each and the links that depict inter-dependency. The experiences discussed by Juganan and Paterson in the South African case in arriving at the appropriate career path framework involved reviewing the availability and suitability of existing

qualifications under the sector education training authority (SETA). Following agreement on all foundry processes involved, the curriculum team in South Africa then finally reviewed the national qualification framework (NQF) levels 2,3 and 4 related to the foundry sector. That was done to determine whether or not all required competencies were met.

A career path framework for foundry processes was then created to include additional standards to facilitate recognition and registration with the Quality Council for Trades and Occupations (QCTO). Juganan and Paterson in consultation with all stakeholders identified the foundry processes as broadly involving the following areas;

(i) Product design and development (including methods, quality assurance etc.)
(ii) Pattern/die making
(iii) Moulding
(iv) Metal management (including melting and casting) and
(v) Finishing operations (including e.g., fettling, welding, heat treatment and surface treatment).

Further, the qualifications agreed as arising out of the above foundry processes were summarised as follows;

(i) Pattern making
(ii) Moulding
(iii) Foundry operation

(iv) Metal production

(v) Tooling and machining and

(vi) Production technology.

Having settled on the qualifications as described above Juganan and Paterson noted that the relevant career profiles that would adequately describe the foundry processes and the required qualifications for the casting trade worker were noted as indicated below;

(i) Foundry patternmaker

(ii) Moulder and coremaker and

(iii) Melter

The core inputs to each of the above were knowledge topics and subjects as well as practical skills and work experience. The material input to the above received benchmarking from the German foundry education system and was made both current and relevant to local South African conditions. Teaching modules suggested for delivery in a small scale under-resourced foundry such as the Kitwe based Fox Foundry are appended in Appendix 5. The modules include aspects of both technology and business principles to assure sustainability of the enterprises.

2.2.11 Technology diffusion as it relates to the small scale under-resourced foundry sector in Zambia

Introduction

The diffusion of technology in any one system is closely related with the diffusion of innovation (DOI) theory originally elaborated upon by E.M. Rogers in 1962 in his book

Diffusion of Innovations. The exact origins of the theory are not so clear but it is significant to state that it is a way of communicating new ideas to social groups over time and that spans all disciplines of study. In his work, Rogers suggested that there were four main elements that influenced diffusion of innovation; (i) *Innovation itself*, (ii) *Communication channels*, (iii) *Time*, and (iv) *Social system*. The process governed by the said four elements must heavily rely on human capital to succeed. Sustainability of an innovation or technology is only made possible with wide acceptance in a particular social system. The process or journey towards adoption must mature or reach a critical point (*mass*) at some stage. In addition, the social system that is aspiring to adopt an innovation or technology may itself be categorised as follows as shown in the figure below; (i) Innovators, (ii) Early adopters, (iv) Early majority, (iv) Late majority, and (v) Laggards.

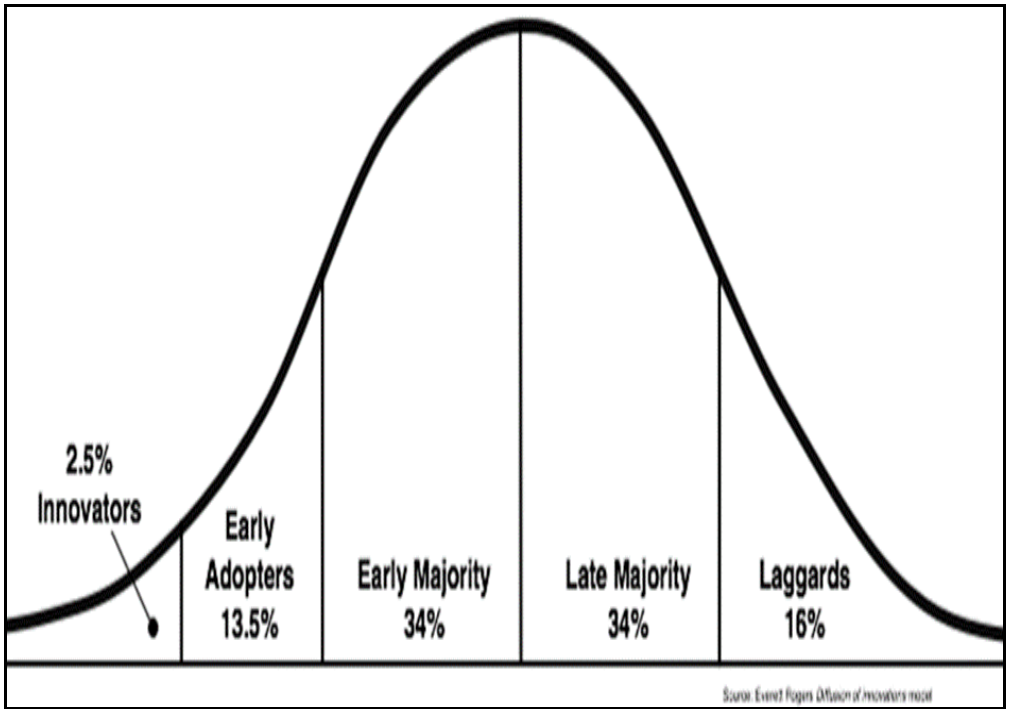


Figure 2.2.11a: The innovation cycle (After Rogers)

Innovators (2.5%) are the first persons to take on any innovation and may also be referred to as risk takers. Little if anything needs to be done to appeal to this category of people. **Early adopters** (13.5%) wholesomely welcome change and are often considered also as opinion leaders and need very little information to spur them on. Early adopters readily embrace change and only require help with implementation manuals. The **early majority** (34%) on the other hand take on new ideas before the average person but rarely assume leadership roles and require evidence that a new innovation actually works. Finally **late majority** and **laggards** (50%) are very sceptical and conservative groups respectively about change or innovation.

This bottom half will only take on new things when convinced others are happy and require special appeal techniques for them to come on board. Rogers and other researchers on diffusion of innovation theory state that there are stages or steps by which an innovation is adopted and subsequently diffused. These steps are identified as *awareness, decision to adopt or reject, initial use* and *continued use of an idea or product*. The last two stages only being possible if an innovation has been adopted. In addition researchers also highlight factors that influence adoption of an innovation as being;

(i) **Relative advantage** as in how new idea is better than current status

(ii) **Compatibility** in terms of answering to the needs of adopters

(iii) **Complexity** with regard to use

(iv) **Triability** to provide for a window of decision before final commitment and

(v) **Observability** in terms of tangible results from an innovation

Technologies or systems in use in small scale under-resourced foundries and innovations possible there in

Kitwe based Fox Foundry, the focus of work during this research represented in good measure the characteristics of small scale under-resourced foundries mostly based on the Copper belt of Zambia. There is heavy reliance on the use of *scrap metal* as an input material whose sources vary with large industries such as mining companies being significant suppliers. The handling and grading of scrap metal is by visual sorting only and chemical composition and other properties are not taken into account at this stage. Melting of the scrap metal is accomplished by use of crucible furnaces utilising used oil from motor vehicles. The delivery and control of the fuel oil to furnaces is rudimentary and there is no ready data on the plants on important things like efficiency of energy use.

All castings are generally done in sand and are of the ingot type or semi-finished. Furnace yields or production are recorded regularly though specific heats involving each output are not identified or identifiable and make the task of diagnosis of faults or implementation of quality measures difficult. Post casting operations involve surface cleaning and limited machining where required. Though not common in similar set-ups, Fox Foundry in particular does manufacture components from its output of bronze castings on request by users. This involves only a small proportion of the bronze production as the bulk of it is sold and delivered in the raw form for finishing by the end users. Throughout the production chain at Fox Foundry, there are no standardised quality control measures used other than just physical checks on final output product. This is despite the fact there are a number of simple to use techniques tried by other entities that may be used improve the production process and final output products.

Temperature measurements on the furnaces using simple calibrated heat sensitive crayons is one such aspect. Accurate temperature monitoring can avoid excessive energy use or on the other hand loss of otherwise useful energy from the furnace. Flow valves can be installed in lines to supply and control heating oil to crucible furnaces and eliminate waste and improve energy efficiencies as another. Another area still is thermal insulation of the crucible furnaces. Furnaces at Fox Foundry and similar small scale under-resourced facilities on the Zambian Copper belt operate furnaces without making use of basic heat conservation measures.

The bulk of Fox Foundry output is sold as raw or semi-finished castings and a limited quantity in the finished form. It is possible for Fox Foundry and others like it to increase the proportion of finished castings sold and with it the value added. That measure however requires more skills and better or more advanced equipment than is currently available at the firm.

Technology diffusion examples or techniques followed

Technology acceptance and its sustainability

Based on the pioneering work of Rogers on diffusion of innovations or technologies, many researchers have added ideas on aspects of technology acceptance and how that technology can be sustained once accepted. In assessing technology acceptance or sustainability, models have been developed that take into account socio-economic and socio-technical characteristics of innovation development and its exploitation. As in several literature, the words innovation and technology in this discussion are used inter-changeably. Examples of assessment models include the Integrated Acceptance and Sustainability Model (IASAM) by Aizstrauta *et al* (2015), Technology Acceptance

Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) to name only three. Many of the assessment models are based on complex user surveys and generally examine only the first aspect of acceptance and not its sustainability but the IASAM model combines both. All these approaches tend to have their unique strengths and limitations due to the individual emphasis they make. Typical in the emphasis could be the analysis of a technology life-cycle in which different stages of an innovation are identified.

The IASAM model can evaluate a technology's acceptance and its sustainability at any chosen point of time of the technology life-cycle and therefore forecast the chances of the technology to attract users and achieve the aims of its developers according to Aizstrauta and co-authors. The IASAM model can be used for existing technologies and systems as well as assess technologies in the development process and follows a number of steps to arrive at a defined criteria. The evaluation steps then lead to an IASAM index noted as follows;

$$IASAM_{index} = \frac{\sum_{j=1}^{n} A_j + \sum_{i=1}^{n} B_i}{(N-C)*7} \quad \text{.....2.2.11(i)}$$

Where A and B are specific survey response values, N is the total number of questions in a survey and C are those questions with a response of not applicable (N/A). The full IASAM methodology is then used to interpret the final result. Two results can immediately be read from the index; sustainability and credibility of the result.

The IASAM model can also be used to make multiple evaluations over the life-cycle of an innovation or technology from which results the evolution of a technology can be compiled.

Skills driven technology diffusion

The diffusion of a particular technology into an entity (production or just general public) must be preceded by its innovation or creation. The process of technology innovation and diffusion has many facets to it such as characteristics of its users and producers, technology quality improvement and its user demand among other factors. Mukoyama *et al* (2003) define machine users (or of capital goods) as a worker-firm match in their research titled "A theory of technology diffusion". Skills possessed by workers or machine users are key factors that come into play during the technology adoption process according to the authors cited above. Mukoyama *et al* developed or adopted a model to assess the technology adoption and diffusion process from the perspective of economics or supply and demand dynamics.

Consider one particular machine of generation i with a capability of producing a surplus b_i when put into production. At its best in production, the machine i will be said to have an error rate Θ_i which declines (or improves) over time with quality improvements to the machine. Regardless of skill levels, workers using the same machine *i* are exposed to the machine error with the same probability but the higher skilled ones are able to cope with machine error problems a lot better than those with less skills. The profit to be realised by such a machine user can then be expressed as below;

$\pi_i(s, b_i\Theta_i) = b_i - g_i(s, \Theta_i)$ of *i*th generation (*i* = 0, 1, 2, 3, …) ……. 2.2.11(ii)

Where $g_i(s, \Theta_i)$ represents the cost of handling errors and this function will naturally decline with increasing skill level and on the other hand increase when Θ_i increases.

The profit function described above is only favourable to the machine user when the condition below holds true;

$\pi_i(s, b_i\Theta_i) \geq 0$ for $s \geq m\Theta_i$…….. 2.2.11(iii)

Equation 2.2.11(iii) implies that a machine user remains profitable when only he possesses or deploys large enough skills relative to Θ_i. Conditions that will render equation 2.2.11(iii) unfavourable are the extreme ones such that;

$g_i(s, \Theta_i) > b_i \; if \; s < m\Theta_i \; and \; g_i(s, \Theta_i) = 0$ …….. 2.2.11(iv)

for $m > 0$ and being a constant parameter.

Mukoyama *et al* therefore suggested that the potential demand for a particular machine of technology level *i* and possessing error rate Θ_i and when priced at p_i can be noted as below;

$D_i(p_i, \Theta_i) = 0 \;\; if \; p_i > b_i$ and alternatively

$D_i(p_i, \Theta_i) = N\,[1 - F(m\Theta_i)] \; if \; p_i \leq b_i$

Where $D_i(p_i, \Theta_i)$ is known as the potential demand for technology or machine *i* and $F(m\Theta_i)$ is the distribution function of skill. All new technologies or capital goods are subject to competition with similar ones in that category and final demand tends to settle in equilibrium. The formulation above clearly shows a distinction between the quality improvement of the existing technology based on a fall in the level of Θ_i and the arrival of a new technology based on an increase in b_i. Quality improvement can

impact demand positively while arrival of a new technology or innovation that boosts performance tends to increase the reservation price of the output from the use of that technology or innovation.

Role of machine quality in technology diffusion

From the tool or machine maker's point of view, producing a higher generation machine or (*i* + 1) *th*-generation machine with higher performance that yields (b_{i+1}) surplus value can be considered innovation. The machine producer can quite easily disregard or abandon production of older generation ones of the type (*i* - 1) *th* and so on and only maintain two production lines of *i-th* and (*i* + 1) *th* as an example. Mukoyama and co-researchers contend that the (*i* + 1)*th* generation machine may not necessarily yield higher quality in output as it is assumed to start with an error rate of (Θ_{i+1}). The researchers' conclusion on this is that quality can be lost on upgrading and the level of lost quality is a direct consequence of higher performance technology according to the relation in equation 2.2.11(v);

$$\Theta_{i+1} = \Theta_i + c\left(\frac{b_{i+1}}{b_i}\right) \quad \text{.....2.2.11(v)}$$

Where $c(.):(1,\infty)$ is an increasing and continuous function.

Discussion on possible diffusion or acceptance of new ideas or technologies

During the course of this research, a number of ideas on new and better ways of doing things were discussed with Fox Foundry in Kitwe and Heroes Foundry in Lusaka. These included sorting and grading of furnace charge materials, sampling and composition measurement of charge and in-process materials as well as final products and heating fuel usage in the crucible furnaces. Another idea was the use of permanent moulds for enhancement of surface quality and the initial metallurgical structure. Application of

proprietary software for such things as mould filling optimisation (directional solidification) and elimination of hot spots was yet another area of improvement. Although the above ideas and many other suggestions seemed well received by the two foundries, lack of decisive follow up steps on the proposals would be considered an indication of slow diffusion or lack of it altogether based on ideas elaborated upon by Rogers and others cited above.

Concluding remarks

Timely adoption and use of new ideas, techniques or technologies (collectively described as innovations) as would be applicable to the small scale under-resourced foundry process is one way of guaranteeing sustainable production. Based on the experience with some Zambian small scale foundries in particular Fox Foundry in Kitwe and Heroes Foundry in Lusaka, it was observed that innovations that would enhance sustainable production were few and insignificant or lacking altogether. The reasons for that status quo could not be clearly ascertained at the time.

2.3 Methodology development for casting bronze sleeve bearings using expert models

2.3.1 Bearing design starting point

The starting point for bearing design and casting is in examining the loading conditions in the axial (thrust) or radial (journal) directions and determining the maximum loads likely to be encountered in the operating environment. In addition surface velocity of the moving components, in this case the rotating shaft, should be evaluated including a value for the maximum load-at-velocity (PV) factor. The objective in a casting process is to produce a structure that is durable and has a low coefficient of friction and an

acceptable temperature operating range. The desirable product is pore free and highly dense grain structure.

2.3.2 Specific models and areas of application

Iqbal *et al* (2012) in their study of "Mold design optimization for sand casting of complex geometries using advanced simulation tools" noted excellent agreement between simulation results for casting an impeller and those obtained from actual test castings. In the conclusions of the authors, the elimination of the costly hit and trial practices found in conventional casting design was significant with the use of their chosen expert simulation tool. As such simulation packages are a valuable tool for competent foundrymen. They however do not replace the need for competence and outputs are highly affected by input. Daws *et al* (2008) reported a process selection technique for component manufacture based on the use of the Fuzzy Logic (FL) algorithms in arriving at the appropriate choice of materials and the production process. The Computer Aided Casting Process Selection (CACPS) assesses the degree of compatibility of the selected criteria and ranks them according to pre-set values.

The FL approach is now a widely accepted method of treating data that may be subjective or imprecise in a mathematical way and use the outcomes to implement a decision. The FL approach as a tool for data treatment was also considered useful for non-automated processes where a factor like pour timing was considered critical. Akarte and Ravi (2007) also applied the FL technique to assess what they termed the product-process-producer challenge. The ultimate objective in getting the right product is in optimising the product's functionality and manufacturability. Akarte and his co-researcher went on to define up to twenty five (25) criteria that described fully the tri

challenge of product-process-producer matrix and used a rating method to assess each criterion.

Karthik *et al* (2002) worked with a web based package called Materials Process Advisor (MPA). This considered ranking casting product quality criteria such as dimensional tolerance, surface finish, thick and thin sections and shape complexity to choose the best method of casting. The MPA uses a weighted approach method to assess quality parameters in the product providing a process that satisfies all quality aspects. Some input property, such as surface finish, may not be important all the time in a production cycle or at least not as important as another criterion being considered.

Darwish and Tamimi (1996) developed a computer based expert system to help arrive at an appropriate casting process. This takes into account three major attributes of design, production and manufacturing. Trade off attributes were generally found to be in the form of cost and other business issues. The discussion above showed that there were a number of expert systems available to guide production of castings in their various forms. It is important that at the design stage of a casting, the product design criterion is fully discussed with the foundry personnel to ease the aspect of manufacturability while keeping production costs as low as possible.

2.3.3 The Taguchi model

The Taguchi philosophy has three areas;

(i) Design quality in, don't inspect,

(ii) Quality achieved by reducing variances and

(iii) Quality is cost effective

The Taguchi approach also specifies three phases of quality control and are;

(i) System design

(ii) Parameter design – experiment design and

(iii) Tolerance design

The Taguchi design of experiments is based on evaluating all possible and probable (80:20) combinations and interations. The main objective in this approach is based on answering three questions noted as follows;

(i) What are the optimal conditions?

(ii) Which factors have the largest influence on the outcome and

(iii) What is the expected result at optimal conditions?

The concept is easy to apply (standard arrays are published) and yields constant results and leads to experimental efficiency. In conclusion and to successfully use this approach the steps are listed as follows;

(i) Identify the perceived important controllable factors,

(ii) Use standard orthogonal arrays to design experiment suite,

(iii) Experiment

(iv) Plot graphs to show interfaces and confirm interactions

(v) Analyse variances

(vi) Optimise factor inputs

2.4 Review of competing production techniques

2.4.1 Use of expert systems

Application of the knowledge based approach (expert systems or software based tools) greatly assists in process and product evaluation. The earlier the tools are applied in the

design or production stages the better. The approach has potential of saving resources and contributing to product improvement. The techniques discussed in section 2.3 however apply more to the already established industries where as the upstarts or smaller entities require a modified approach such as aconsultance service.

Boothroyd *et al* (1991) in their publication titled "Research program on the selection of materials and processes for component parts" showed that a limited knowledge of materials and processes by designers in the early stages of product development usually resulted in missing out on opportunities for arriving at cost effective products. Boothroyd and co-workers were attempting to develop a systematic method of considering and ranking various feasible material and process combinations for manufacture of a part in terms of a given criteria. Boothroyd *et al*, supported by other researchers, stated that although the cost of design was only around 5% of total product cost, decisions made at the conceptual design stage affected up to 70% of the overall cost of the product.

It was noted that material and process knowledge among designers was limited to domains familiar to the designers. That situation made it difficult to attain product cost effectiveness. Part of the solution in the Boothroyd study lay in utilising a software programme that optimised processes and accessibility to suppliers of those services, a Rapid Application Development (RAD) tool.

A manufacturability evaluation on the preliminary design of a sleeve bearing is important. Product characteristics may be modelled early in the design stages to estimate final cost. Finally, evaluation should be supported by a full product description, manufacturing process capability data and a knowledge base for estimation

of product cost. In the light of availability of the above tools and techniques, SURFs are in a position to take advantange of appropriate commercial agreeemnts to manufacture replacement products of principal suppliers or OEMs.

2.4.2 The role of CAD in design and simulation

The design of casting methods seeks to ensure within the limits of minimising material input that;

(a) The die geometry and material of fabrication must be adequate for the purpose.

(b) The cast part must be complete.

(c) The cast part must be whole, stable and fused,

(d) The liquid flow rate at the die gate must be correct,

(e) The gate cross section must avoid local freezing,

(f) An even feed into the die is needed and

(g) Shrinkage porosity needs to be accommodated.

This is where simulations assists have added value when operated by experienced foundrymen. Liao *et al* (2011) stated in their paper on Casting CAD/CAE automatic optimal riser design technology that an initial casting design was important in order to apply the technology successfully. The user's professional and technical experience was an important precondition. The authors acknowledged that there were practical limitations to attaining a fully optimal casting design as factors and parameters involved were numerous. Risers and other parts of gating systems designed based on experience alone were unlikely to be successful in achieving good feeding. Many times also the designs resulted in being so conservative that more metal than required is consumed.

The foregoing is important in that it offers a way of helping small foundries determine desirable feed and riser configurations that minimise yield losses.

A number of techniques employed in CAD design simulation for risers, feeders or other casting requirements include the modulus theory, liquid volume method, proportion method, Q parameter method, cubic equations method as well as the perimetrischen quotient method. The modulus or local modulus method is widely used through the application of the isolated liquid regions (ISLs) approach. The software used by Liao *et al*, InteCAST, was able to track the volume and surface area of every ISL in the melt and could output the solidification time as well.

The tracked parameters included melt volume, surface area, solidification time and location of ISLs. The modulus in feeder and casting may be expressed as;

$$\frac{V_c}{A_c} = \frac{(V_r - \varepsilon (V_c + V_r))}{A_r} \qquad 2.4.2(i)$$

A_c, A_r are the valid cooling surface areas of casting and riser

V_c, V_r are the volumes of the part of the casting that is fed and riser

ε is solidification shrinkage rate of the alloy

It is known that $A_r = \frac{V_r}{M_r}$ 2.4.2(ii)

$$f = \frac{M_r}{M_c} \qquad 2.4.2(iii)$$

M_r, M_c are the theoretical moduli of the riser and casting.

Substituting (2) and (3) into (1) will yield;

$$\frac{V_r}{V_c} = \frac{\varepsilon}{(1 - \varepsilon - f^{-1})} \qquad 2.4.2(iv)$$

If $q_r = \frac{V_r}{M_r^3}$ and 2.4.2(v)

$$q_c = \frac{V_c}{M_c^3} \qquad 2.4.2(vi)$$

where q_r , q_c are the perimetrischen quotients of the riser and casting

Substituting (2.5) and (2.6) in (2.4) will yield;

$$(1 - \varepsilon)\frac{V_r}{V_c} - (\frac{q_r}{q_c})^{1/3}(\frac{V_r}{V_c})^{2/3} - \varepsilon = 0 \qquad 2.4.2(vii)$$

The approximate solution of above equation (2.7) is then;

$$\frac{V_r}{V_c} = \frac{q_r}{(1-\varepsilon)^3 q_c} + 3\varepsilon - (\frac{q_r}{q_c} - 2)^{1/3}\, x\, 10^{-2} \qquad 2.4.2(viii)$$

Flender and Sturm in their "Thirty years of casting process simulation" report showed evidence of acceptance of the technology in the foundry industry and that it would not be long before the practice of trial and error was completely eliminated in the sector. That would of course depend on access and affordability of simulation services. The simulation process utilises a set of differential equations applying mainly the finite difference and volume methods, FDM and FVM, of either structured or unstructured tetra, penta or hexahedrons. The authors further say that there is no ideal route for simulation in a given situation but only the best adjusted solution for the specific requirements of the casting process and foundry. They add that the appropriate term to be used is casting simulation as opposed to solidification simulation. That has been so because the initial focus of the work was on heat transfer. Mould filling and other aspects are however equally important and have a great impact on the solidification process itself and all together meriting the term casting simulation. It was mentioned that the reliability of any method used must be checked.

A clear understanding of an alloy's feeding behaviour as well as method of founding to be used was important in developing a material specific simulation model as opposed to sole dependence on temperature distributions. Altering one process parameter during casting can impact many quality features. One way to get out of that is to utilise a multi-

objective autonomous optimisation according to Flender and colleague. The simulation tool is turned into a virtual experimentation area where changes to pouring conditions, gating design and process parameters ca then be used to satisfy the overall objective.

Cho and Choi (2011) of Korea Institute of Industrial Technology (KITECH) in their paper "New era of simulation services for SMEs" were promoting the use of 'rent and use anywhere' as opposed to traditional 'buy and use' applications. KITECH's Internet Simulation Center (ISC) programmes making use of cloud computing and highlighted several protocols in achieving access to simulation services for small users.
The actual method of doing so was missing from the write up and the authors did not respond to an email enquiry posted on 20th November, 2014.

2.4.3 Modelling and simulation of microstructure

Microstructural predictions in alloys rely on numerical models that use known algorithms which themselves are based on a set of equations looking at how phases contained in a microstructure are transforming or behaving at a given time according to Chandran B.G. and co-worker in a paper titled "Prediction and optimisation of microstructure in material processing". Phase transformation with time is effectively controlled or governed by the material's cooling rate. Solidification and microstructural analysis can therefore be performed by using actual or assumed process parameters. The techniques used to solve differential equations that predict microstructure (referred to as the 'forward problem') and optimisation of process parameters governing microstructural evolution ('inverse problem') can be complex. In the example of heat treatment of a carbon steel austenitisation is said to be achieved when a specific transformation line AE3 (^{o}C) is attained and crossed which is considered a linear function of the constituent elements in the alloy.

In the case of the steel above, the ferrite phase is used to track the progress of transformation during heat treatment in the form of a time dependent equation of the kind below;

$$\frac{dX}{dt} = f(X) \qquad 2.4.3(i)$$

Where *X* is the phase fraction of interest and in this case is ferrite, t is the time variable and *f(X)* is itself a complex function involving the undercooling, *ΔT*, which is (*AE3 – T*) and *G*, the ASTM grain size number. The ferrite fraction, *X*, according to Chandran is designated as;

$$X = \frac{X_f}{X_{fe}} \qquad 2.4.3(ii)$$

Where Xf and Xfe are the actual and equilibrium ferrite fractions at time t. Equation 2.4.3(i) can be re-written to indicate the following;

$$\frac{X - X_o}{\Delta t} = f(X) \qquad 2.4.3(iii)$$

If a residual function, R, is defined as follows;

$$\frac{X - X_o}{\Delta t} - f\,(X) = R \qquad 2.4.3(iv)$$

In reality the residual is the incremental or additional and not absolute quantity of ferrite during the transformation of phases at any given time t and that is due to the f (X) correction in equation (2.12). Differentiating (2.12) with respect to X will yield a result that allows iteration in the simulation process where X is updated by X + dX;

$$\frac{dR}{dX} = \frac{1}{\Delta t} - \frac{df}{dX}(X) \qquad 2.4.3(v)$$

The iteration is continued until a new value of residual R continually updated by X reaches a preset tolerance limit. The microstructure in a casting is impacted by its design variables collectively represented by the symbol ϕ. The ratio of actual and equilibrium ferrite, X, may therefore be resolved with respect to optimisation of the design variables thus;

$$\frac{\partial X}{\partial \phi} = -\left[\frac{\partial R}{\partial X}\right]^{-1}\left(\frac{\partial R}{\partial \phi} + \frac{\partial R}{\partial X_o}\frac{\partial X_o}{\partial \phi} + \frac{\partial R}{\partial T}\frac{\partial T}{\partial \phi} + \frac{\partial R}{\partial T_o}\frac{\partial T_o}{\partial \phi}\right) \qquad 2.4.3(vi)$$

Where X is the phase content, R the global residual as defined in equation (2.12), ϕ is the collective design variable and T_o and T are the temperatures at the beginning and end of the time increment. The form of the kinetic function, f(X), referred to equation (1) can also be expressed for the global residual R;

$$\frac{dR}{dT} = yz.f(R) \qquad 2.4.3(vii)$$

Where f(R) is itself a function of the ASTM grain size number G, the undercooling ΔT and composition of the important alloying elements. In the case of leaded tin bronze, the material being considered for bearing sleeve casting in this research, the parallel or equivalent phase in the copper alloy of interest would be delta equivalent or Cu31Sn8.

According to Smoljan *et al*, the decomposition or transformation of a high temperature phase in a metal such as during the heat treatment of steel can be modelled in three ways. The first is using the continuous cooling transformation (CCT) diagrams, the second involves application of the Scheil Additivity Rule (SAR) and the third makes use artificial neural networks (ANN). Accurate use of the CCT diagrams in conjunction with mechanical data can yield information that sheds light on the proportions of the various phases in an alloy. The SAR has more than one format; the first is based on the proportion of transformed phase, X, say in a heat treatment operation and this is based on the Johnson-Mehl-Avrami transformation criteria and the second one the SAR rule itself.

$$X = 1 - \exp(-k\,t^2) \qquad 2.4.3(viii)$$

Where X is for instance the volume fraction of austenite transformed isothermally, k and n are rate constant and time exponent respectively). Non-isothermal transformation however will adopt the following form;

$$\int_0^t \frac{dt}{\tau(X_o,\ T)} = 1 \qquad 2.4.3(ix)$$

Where $\tau(X_o, T)$ represents the isothermal transformation time for X = Xo at a temperature T, and t is the total transformation time. The SAR says that the non-isothermal transformation kinetics are a total sum of the individual series of isothermal transformations. The volume fraction of austenite formed using the above example may be calculated as follows;

$$\Delta X = \frac{\Delta t_i}{\tau\,(T_i)} \qquad 2.4.3(x)$$

Where $\tau\,(T_i)$ is the isothermal transformation time at a temperature *Ti*. The SAR can also be applied in conjunction with the Jominy end quench test results obtained in a

heat treatment procedure. Brodarac *et al* noted a step by step description of the reactions possible during the solidification of an AlSi9Cu3 alloy within the temperature range 609 to 507 ^{o}C. In the work above, Brodarac used a method of differential scanning calorimetry (DSC) to perform thermal analysis on a number of the aluminium alloy compositions. Phase transformation points or intervals and enthalpies of the phases were then obtained by repeated heating and cooling of the test materials. Both light and electron microscopy were used on the thermally analysed samples for phase identification and noting all the reaction equilibria. In the case of CuSn11Pb1Ni1 (or approximated as CuSn11), the material investigated in this research, the possible reactions during solidification would be with various alpha, beta, gamma, zeta, delta and epsilon taking part.

Table 2.4.3a: Known solidification sequence of leaded tin bronze
(projected from the binary copper–tin equilibrium phase diagram)

No.	Reaction	Temp. (^{o}C)	Comments
1	$L \rightarrow \alpha\ (Cu_{10}Sn) + L\ (Cu_{20}Sn)$	1025	Dendrite network development
2	$L + \alpha \rightarrow \beta\ (Cu_5Sn)$	800	Precipitation of beta phase as first eutectoid reaction
3	$L + \beta \rightarrow \gamma\ (Cu_2Sn)$	750	As a key eutectoid reaction
4	$\gamma + \zeta\ (Cu_6Sn_5) \rightarrow \delta\ (Cu_4Sn \text{ or } Cu_{31}Sn_8)$	588	As another key eutectoid reaction
5	$\alpha + \beta \rightarrow \alpha + \gamma$	586	
6	$\gamma \rightarrow \alpha + \delta$	520	
7	$\delta \rightarrow \alpha + \varepsilon\ (Cu_3Sn)$	350	

Due to the presence of the wide freezing range in commercial bronzes, segregation always occurs and a number of eutectoid reactions are possible as forward and reverse

reactions. The notable ones are those numbered 2, 3, 4 and 6. The compound Cu5Sn or beta phase is unstable and transforms as indicated in 3 and 5. Structures of commercial bronzes generally conform to the transformation in 6 giving a matrix of solid solution copper and a precipitate hard phase of the intermetallic compound, Cu31Sn8. The eutectoid ($\alpha + \delta$) phase appears as characteristic dark pattern sandwiched between large dendrites of solid solution copper or α. Quite often the δ portion of the eutectoid may appear as pale blue. Transformation of the δ phase to a much lower temperature compound, ε, as described by reaction 7 rarely occurs as equilibrium kinetics demand infinitely long periods of time.

Summary

The economic role of small under-resourced foundries such as bearing bronze casters on the Copper belt of Zambia was clear. Fit for purpose sleeve bearings must satisfy composition, microstructural, mechanical and operational requirements. There are a number of factors that are directly supportive of the long term survival of small foundry businesses. The key ones are; a good social and business environment in a country, strategic linkages with more experienced busineses in the sector, adequate government support, training and diffusion of skills and understanding the usage of energy.

In recent years, foundries just like other industry sectors have benefitted from developments in the use of technologies from design of products, testing of prototypes and final production without the need for costly trials. Although acquisition of such technologies is a huge investment initially, pooling together of resources by sector players can help mitigate the financial burden of such an undertaking. Given the reality of low penetration of local mining consumables and spares manufacturers on the Copper belt of Zambia as highlighted in the problem statement helped to define the

areas for literature search as noted in section 2 at the start of the chapter. One of the ways of increasing penetration of small foundry producers into the lucrative mining industry value chain is knowledge and skills delivery in the form of regular short trainings designed for foundry personnel. Appropriate training is an output of this study neglected in previous attempts to help the sector.

CHAPTER THREE

3. Experimental Design and Process Approach

Introduction

The major steps proposed for testing the hypothesis that sleeve bearings could be produced in an under resourced or low level technology facility at a cost that represented value for money were generally in three broad areas. Data was examined from existing literature as well as through discussions and interviews. In addition experimental castings were done at an operating small foundry and in the laboratory examining specific factors.

The three broad areas in which inquiry was made are noted as follows;

(a) Characterisation of the required bearing

(b) Characterisation of foundries capable of producing them and

(c) Proposition and testing of a workable methodology for producing bearings

Visits were made to facilities in both South Africa and Zambia within the confines of limited access to private premises (refer to **Appendices 1, 2** and **3**) for summary reports of the visits. The visits were complimented with discussions on operations of production facilities and the economic environment obtaining in each country. The major objective of visits was to familiarise with foundry processes and practices at the companies where permission was granted. For logistical reasons however, samples of new and used bearings were only collected in Zambia. The testing of a proposed casting methodology involved manufacturing of a permanent mould and testing it out at an

operating foundry. The test castings from the permanent mould were then subjected to laboratory analysis as were the collected bearing samples of new and used materials.

A prototype short term training programme for essential foundry production personnel was developed during the course of this research to contribute to skills development in the area of metallurgical quality control. It was assumed that trade qualifications in pattern making, moulding, melting and casting in Zambia's national programmes were adequate in many respects and training proposed here was therefore only complimentary. Lessons learnt with regard to using permanent mould casting as opposed to the current practice of gravity sand casting for sleeve bearing production were incorporated into a module on personnel training. The above considerations were informed by the following process approaches;

(a) New bearings for earth moving plant from certified manufacturer(s) in RSA and used ones from operating plant in Zambia were tested to determine required quality (composition, microstructure, surface and physical properties including tribology and wear properties).

(b) Consultations were made with local and international through the World Foundry Organisation (WFO) foundry industry members in small foundries. Visits were undertaken to six foundries in RSA and Zambia identified on the basis of their low level technologies used in production to determine a profile of characteristics of successful operators.

(c) A step by step draft working guide appropriate to a small under resourced

foundry on the casting of a standard bearing was proposed. Use was made of observations, consultations and secondary data from literature based on identified key operating factors. That was mainly accomplished by informal engagement and discussion with production personnel.

(d) One of the variables associated with sustainability is energy management and in this study considered key. In principle, when the costs of energy and capital were low, the tendency was to purchase low cost equipment which tended to be energy inefficient. Secondly energy usage practices were rudimentary. However now that energy is expensive and affects the operating cost significantly, energy conservation has become essential.

(e) Cash flow to a SURF is critical and is a major factor of sustainability. One of the concerns of small scale foundries is working capital. The major cost of a casting is represented by the metal content. Security of metal and other materials is equally paramount for sustainability. Scrap metal is readily traded. Buying of metal as immediately needed is not clearly cost effective on the other hand – but overcomes concerns about theft.

(f) A tolling arrangement of a SURF business with a major consumer can address concerns highlighted in items l and m and possibilities do exist in Zambia but require to be negotiated for skilfully. Konkola Copper Mines Plc agreed in principle to go into a tolling arrangement with a bearing bronze producer and

address the many challenges associated with quality of products (meeting with CEO at ZIMEC 2017, June 2017).

3.1 Characterisation of the required output bearings

Sample materials were collected from three entities on the Copper belt of Zambia namely Fox Foundry, Mopani Copper Mines and Non-Ferrous Metal Works of Zambia and from one foundry in Lusaka called Heroes Foundry. Samples collected from all of the above are in here referred to as ***Foundry Materials*** and were in turn classified into individual groups depending on their usage. Foundry materials in this study were different from those that were directly cast in the laboratory and here called ***Castings***. Initially and during June 2013 a few random samples of both new and used bearing materials were made available for analysis as a preliminary step.

Samples included sixty (60) kilogrammes of a secondary crusher liner bronze material that was to be used as a base material for performing laboratory experiments by alloying with tin, lead and nickel in varying proportions. Over eighty (80) samples were collected and were appropriate analysis was undertaken. A three letter code was given to each sample examined and the full identification of all samples included in **Appendix 6**. Owing to limitations on size and shape of the samples collected, tests such as the tensile property could not be performed. A Table on *Laboratory test readings of chemical composition, hardness and friction for bearing samples* is shown in **Appendix 8** for reference.

3.1.1 Analysis on new, used and laboratory cast bearing samples

Materials used: Bronze collected from various sites on the Copper belt of Zambia that included sections of cast ingots, used bronze parts to be recycled and a discarded bronze liner from a secondary crushing machine. The liner was used to prepare samples for laboratory castings.

Methods: Collected samples were categorised by function or use. The samples were then subjected to chemical, hardness and friction testing as well as microstructural analysis. Descriptions of the tests done are elaborated upon in the next paragraphs.

Testing procedure followed: Chemical analysis on all samples was by atomic absorption spectrometry. Sample is dissolved in acid media and suitably diluted for reading against the standard metal elements to be tested.

Collected and laboratory cast samples were tested for chemical composition with respect to copper, tin, lead and nickel. The four elements are the primary constituents of leaded tin bronze of Copper Development Association group III alloys. Other tests were hardness and friction during wear. Chemical composition is the primary driver for post casting microstructure and properties. Hardness and friction on the other hand are directly dependant on one another and both these and chemical composition are essential in bearing performance (Stribeck curve, Fig.2.1.7a).

Chemical analysis was done using a Varian Spectra AA 50 atomic absorption spectrometer. Hardness measurements were conducted using a Future Tech micro-hardness tester FM-700 using a test load of 1kg weight by surface indentation of test

samples. The result was given as resistance to load penetration by the measured size of the diamond indenter. Sliding friction was evaluated using a CSM Instruments ball-on-disk tribometer for flat specimens using controlled temperature and humidity. Friction test parameters used were as recommended in laboratory equipment manual guided by technical personnel and were; load of 5N, linear speed of 0.21m/sec, distance covered at 100 metres and data acquisition rate at 1hz. Average temperature and humidity recorded were ±25 deg.C and 48% respectively. The ball used in the friction tests was chromium steel of 6mm diameter.

Microstructural analysis was done on a Leica CTR 6000/DM 6000 M optical light metallurgical microscope supported by a computer image processing application. Preparation for microstructural analysis involved 1 micron final diamond paste polishing and etching using ferric chloride. A combination of distilled water and alcohol was used for final cleaning. No other microscopy techniques were applied in this study. There were limitations on other useful mechanical tests such as tensile and impact strengths. The nature of the samples collected were too small in size and of inappropriate shape to extract standardised samples to be used in those tests. The above procedures and methods were used during laboratory testing and characterisation of the collected samples for the purpose of this study.

3.2 Characterisation of foundries capable of producing sleeve bearings

Method used to assess capability: Description of type of foundry in place (jobbing or production), furnaces used and fuel type as well as alloys treated. Other aspects involved were skills of personnel manning the facilities. Visitation reports are given in Appendices 1, 2 and 3.

At the time of collecting new and used bearing material for analysis, a description of a foundry with the requisite plant and other resources capable of producing sleeve bearings was proposed as noted here. The foundries visited (June 2013, January 2014, July 2014 and January 2015) were basically using gravity sand casting and doing single castings of about 200kg at a time. Oil fired crucible furnaces with a capacity of 500 kg molten metal were used, these mainly were dependent on recycled or used oil. These small foundries like other businesses of a similar nature are impacted by the economic environment around them. Inflation and interest rates, a good infrastructure and supportive tax regimes are important.

The facilities had no quality control procedures in place to check raw material input, materials in process and the final products. An important aspect of production is energy utilisation. Both Fox and Heroes foundries were using used diesel oil for firing their furnaces but did not have an accurate way of assessing actual usage of fuel oil per quantity of metal melted. An attempt was made at Fox Foundry during the course of research to measure energy utilisation using production figures of metal and quantities of used oil purchased during a two year period.

3.3 Design a mould and test it by producing a typical bearing

Method used to produce a mould: A computer aided design (CAD) was used as first step for mould design. This was followed by casting simulation of mould and bearing sleeve using suitable software as described in the next paragraph. Grey cast iron and high carbon steel were materials for two types of moulds for trial castings at Heroes Foundry and the laboratory at the University of Johannesburg.

A permanent mould design based on typical size was conceived and manufactured using grey cast iron. The mould assembly was gravity fed with the options of testing other methods of feeding metal where that was possible (see CAD drawing of mould assembly in **Appendix 7**). The CAD files had electronic versions of the permanent mould geometry in a suitable interface format called STL. That was required in order to use the MAGMASOFT solidification modelling tool. The images displayed in Figs.3.3a to 3.3d show part of the preparatory steps to producing a typical permanent mould. Images in Figs.3.3e to 3.3h show part of equipment set up at the University of Johannesburg laboratory foundry and a small permanent mould used at the site.



Figure 3.3a: Wooden pattern of the mould



Figure 3.3b: Newly cast permanent mould
(Zalco Ltd., April 2014)



Figure 3.3c: Female assembly to be machined



Figure 3.3d: Male mould part on a lathe
(Unza, July 2014)



Figure 3.3e: Laboratory mould with crucible



Figure 3.3f: Mould in sand ready for casting
(UJ foundry lab, May 2015)

The steel mould in Figs.3.3g and 3.3h had a cavity measuring 40 mm at the top declining to 30 mm at the bottom in a taper and a height of 60 mm. The barrel and base formed the two parts of the mould and would be assembled as shown in Fig.3.3h.



Figure 3.3g: Mould barrel and base



Figure 3.3h: Assembly of barrel and base

The two types of moulds *i.e.* the large cast iron mould and the smaller steel mould shown above were used for test castings. The factors or parameters proposed to be tested were; defined composition of the bronze (obtained by alloyng parent materials and not by scrap analysis and composition fitting) with respect to tin, temperature of casting, duration of pouring, mass or volume of casting and the feeding method used.

It was proposed that each of the five factors be set at three levels in accordance with a proposed testing model. The model uses a matrix approach and is one way to perform trial experimental castings without the need to do the full compliment of test runs as is required in a conventional factorial design model (refer to section 2.3.3). The traditional factorial design method entails a lot more experiments in a single trial. Using the matrix model method, twenty seven (27) experiments need to be carried out in this case as opposed to a total of 243 runs in a single trial. The Table 3.1 shows only the first nine using the matrix model as opposed to a factorial model. A full table is in **Appendix 4**. The full matrix table is generated using a statistical software such as Minitab by specifying the number of factors and the number of levels at which those factors will be varied. The matrix model calculation then optimises the experimental runs and generates a table part of which is seen Table 3.1.

Table 3.1: Matrix model layout

No.	Composition (%Tin)	Temperature (Deg. Celsius)	Pouring time (Seconds)	Weight (Grams)	Feed
1	7	1080	2	1	1
2	7	1080	2	1	2
3	7	1080	2	1	3
4	7	1100	3	2	1
5	7	1100	3	2	2
6	7	1100	3	2	3
7	7	1150	4	3	1
8	7	1150	4	3	2
9	7	1150	4	3	3

The test parameters in Table 3.1 based on the five factors and varied at three levels as chosen earlier are further explained as follows in the Taguchi simplification of the factorial experimental design;

Composition: Tin content of bronze in percent at 7, 11 and 14%.

Temperature: Casting temperature varied at 1080, 1100 and 1150 ^{o}C.

Pouring: Duration of laminar pouring where '2' represents a shorter time than normal, '3' normal pouring time and '4' a higher than normal pouring time in seconds.

Mass : Mass or volume of casting using '1' lower than optimum size at 35 grams, '2' optimum size at 40 grams and '3' above optimum size of casting at 45 grams.

Feed: Feeding method by '1' direct gravity pour, '2' basin or side feed.

As a complimentary step to the above procedure, use of a commercial modelling software, MAGMASOFT, was adopted. The objective was to model the solidification and stress profile of the bearing bronze within the permanent mould cavity as casting is taking place. Secondly, the permanent mould design itself as finalised in a CAD software called SolidWorks was subjected to similar analysis to ascertain the feasibility of its production. MAGMASOFT was used to simulate both the design and the casting processes of both the mould and sleeve bearing in order to detect potential errors in the solidification and stress profiles. Simulation of design and casting are considered an integral part of computer aided engineering (CAE) for the purposes of establishing criteria that could be extended to the teaching or training modules proposed in this

study. In all the cases, there were no licences acquired for any of the softwares used during the study but rather leased on short term basis at resident computers at University of Johannesburg where they were available.

Summary

The experimental procedure was based on looking at the characteristics of both foundry materials and those that were cast in the laboratory. These included composition of major elements, microstructures and testing mechanical properties of hardness, friction and wear. Attributes of small scale foundries just as workable methodologies capable of producing saleable bronze sleeve bearings were also looked at.

CHAPTER FOUR

4. Results

Introduction

The results presented in the following sections are from analysis of new and used bronze sleeve bearing samples obtained from various sources as stated in section 3.1. The characteristics of a small scale under-resourced foundry (SURF) with the potential of producing fit for purpose bronze sleeve bearings are suggested. A proposed methodology for achieving a near net bronze sleeve casting at a cost that represents value for money is given. The methodology was the basis for field testing at an operational foundry, Heroes Foundry in Lusaka, Zambia. Lastly the use of simulation in optimising design for casting and the casting process itself is presented for a grey cast iron permanent mould and the test alloy CuSn11Pb1Ni1. The objectives in using the simulation was to optimise the test parameters applicable in conventional trial castings using the permanent moulds shown in Figures 3.3e, 3.3f and 3.3g above. That was so especially with regard to commercial mould production (3D printing as possible option) and the setting of an optimum cooling criteria for the alloy in question.

4.1 Laboratory test results of foundry materials and castings

4.1.1 Summary of test results

More than one hundred (100) samples were collected to include two (2) that were directly cast at a foundry in Lusaka and forty cast at the University of Johannesburg laboratory foundry. Not all tests were achievable on some of the collected samples mainly due to insufficient size of the material. *Foundry materials* were grouped according to use and coded as follows; standard machining stock (StdMStoc), hydraulic

stock (SHS), mining stock (SMS) and processing stock (SPS). Experimentally cast materials or *castings* were grouped and coded as; foundry cast (FOLC), laboratory high cast (LHTC), laboratory medium cast (LMTC) and laboratory low cast (LLTC). Composition, hardness and friction variations for the key elements of copper, tin, lead and nickel are displayed in Table 4.1.1a. The mean values for the key characteristics of the foundry materials were compared with those for the target material, C93200, and how they varied from lowest to the highest for each as well as their respective deviations. It was significant that the key elements of tin, lead and nickel were not in compliance with the target material and had an impact on the properties of hardness and friction.

Table 4.1.1b shows a summary of chemical composition, hardness, friction during wear and microstructure of some selected samples. Samples in table 4.1.1b include all categories of foundry materials and numbered 1 to 18. Original equipment manufacturer (OEMs) bearings or materials included those used as input for machining operations (StdMStoc), general hydraulics use (SHS), mine hoists operations (SMS) and mineral processing equipment (SPS). The results displayed in here were used to do the summary given in Table 4.1.1a. All foundry materials showed similar trends of departure from target composition as was in alloy C93200 and ultimately impacting on hardness and friction properties.

The table also includes those that were cast in a foundry and laboratory and designated as FOLC, LHTC, LMTC and LLTC. The full Table of results for the measured properties are in **Appendix 8**. Samples numbered 1 to 65, with the exception HFC and HFD, were collected from foundries visited. Samples 66 to 106 were cast at the

University of Johannesburg laboratory foundry. All one hundred and six samples are displayed in **Appendix 6**. Bronze samples collected from foundries constituted several types. The OEMs quality types were from various sources. Nearly all of OEMs samples were collected from Fox Foundry in Kitwe. As Fox Foundry did not have a quality system in place, it was not possible to distinguish between the different types of bearings in terms of grade or usage. The bearing materials cast locally at the foundries were then constituted from a mixture of the scrap OEMs without regard to type or grade.

There was a limitation to samples collected for analysis. Mining companies such as KCM had dedicated suppliers of bearing components for certain plant. A request to have samples of bearings from such end users was not fulfilled by KCM despite several assurances from the company and follow ups during the course of this research. A request for samples of unused OEM bearings in South Africa from target companies was also made earlier on during the course of this work but was unsuccessful.

In addition owing to constraints with the types of furnaces used at Lusaka and Johannesburg, the matrix model proposal in Table 3.1 of experimental design could not be exploited in full. It was however possible to adjust composition of the target alloy mostly by varying tin content as well as change the temperature at which the metal was poured from the crucible. In all cases the last three parameters of direct gravity pour, mass of the crucible charge or melt and mode of metal feeding remained the same. Turbulent flow of metal during pouring into mould could not be completely avoided although maximum care was excercised. The tested properties on the laboratory castings could not be evaluated against the five parameters suggested in the model for lack of statistical significance as indicated by composition results in Fig.4.1.2e.

Table 4.1.1a: Chemical composition, hardness and friction summary for foundry samples

	Cu	Sn	Pb	Ni	Hardness HV	Coeff. of friction, μ
Minimum	73.3	0.0	0.1	0.0	67.6	0.20
1st Quartile	81.4	1.3	0.3	0.1	84.2	0.20
Median	86.8	5.0	0.5	0.1	97.5	0.40
4th Quartile	90.1	6.8	2.0	0.3	112.7	0.50
Maximum	98.7	14.7	15.1	0.5	227.1	0.70
Mean	86.2	4.6	1.8	0.2	104.8	0.38
Std. Deviation	6.5	3.2	2.9	0.1	32.5	0.16
C93200 reference alloy	87.0	11.0	1.00	1.00	85.0	0.12

Table 4.1.1b: Summary of test results for composition, mean hardness and friction for some foundry and laboratory cast samples

No.	Identity	Chemical composition in percent				Mean hardness in HV, 1kg	Mean friction coeff., μ	Micro-structure
		Copper	Tin	Lead	Nickel			
1	FFA	91.0	6.68	1.36	0.18	71.7	0.42	Type I
2	FFL	89.7	4.56	0.25	0.16	90.0	0.19	Type IV
3	FFN	88.1	1.13	0.30	0.17	92.2	0.62	Type IV
4	FFO	83.7	1.07	0.50	0.49	78.7	0.65	Type IV
5	FFP	87.2	0.58	0.31	0.13	-	-	-
6	HFA	91.4	4.48	1.21	Fe, 0.54	104.2	0.19	Type III
7	FFE	86.9	6.99	0.59	0.14	83.4	0.53	Type I
8	FFF	81.4	7.47	5.88	0.35	162.2	0.28	Type III
9	FFI	84.0	5.28	2.90	0.35	84.4	-	Type III
10	FFK	79.5	6.47	15.10	0.51	106.2	0.54	Type IV
11	FFR	86.3	1.39	0.08	0.02	109.4	0.41	Type III
12	FFS	95.0	0.78	0.52	0.12	84.4	0.35	Type III
13	FOR	86.9	5.91	1.55	0.21	101.3	0.14	Type I
14	FFC	86.8	8.59	0.07	0.07	128.7	0.22	-
15	FFD	84.9	3.94	2.77	0.43	84.2	0.21	Type III
16	FFM	86.8	0.34	0.43	0.42	73.3	0.15	Type III
17	MCA	83.0	6.85	0.45	-	111.1	0.18	Type III
18	MCD	87.6	3.90	0.47	0.10	67.6	0.42	Type III
19	WAA	88.3	2.7	5.82	0.2	67.8	0.24	Type III
20	WAD	71.1	11.16	1.43	1.7	277.9	0.34	Type III
21	WAI	81.0	11.15	2.35	1.31	138.7	0.29	Type III
22	WAN	92.9	2.68	2.97	0.23	66.6	0.26	Type III
23	WAQ	75.9	13.04	2.95	2.44	156.8	0.27	Type I
24	WAW	75.1	9.94	1.94	0.62	119.5	0.24	Type III

Type I: Coarse grains of α-solid solution showing porosity throughout the matrix.

Type II: Fine to coarse grains of α-solid solution with porosity and significant presence of lead globules.

Type III: Fine grains of α-solid solution with little or no porosity

Type IV: Unresolved structure with some porosity and presence of lead globules.

4.1.2 Metal content in foundry and laboratory cast samples

Of the four major elements in the foundry materials tested, only copper content appeared to be close to that expected in the reference composition. The other three elements of tin, lead and nickel did not and that was the case especially in the foundry samples collected. There were no deliberate steps taken by foundries visited to ensure that compositions of the various manufactured bearings were within required limits. It was just by chance that the copper content seemed compliant. In a number of cases the level of copper was even above the 87% threshold. In the case of Fox Foundry, it was observed that high copper bearing materials were readily available for charging to furnaces and making up the desired weights and not to necessarily comply with composition demands. Sorting and selecting secondary materials is part of the training module suggested with this study should address.

All the standard error (SE) bar plots of metal content comparisons between foundry materials and those cast in the laboratory or castings (Figs. 4.1.2a, 4.1.2b, 4.1.2c and 4.1.2d) did not overlap at 95% confidence interval (CI). It is therefore not possible to deduce whether or not the results were statistically significant in the case of metal contents for Cu, Sn, Pb and Ni on the basis of error bars alone.

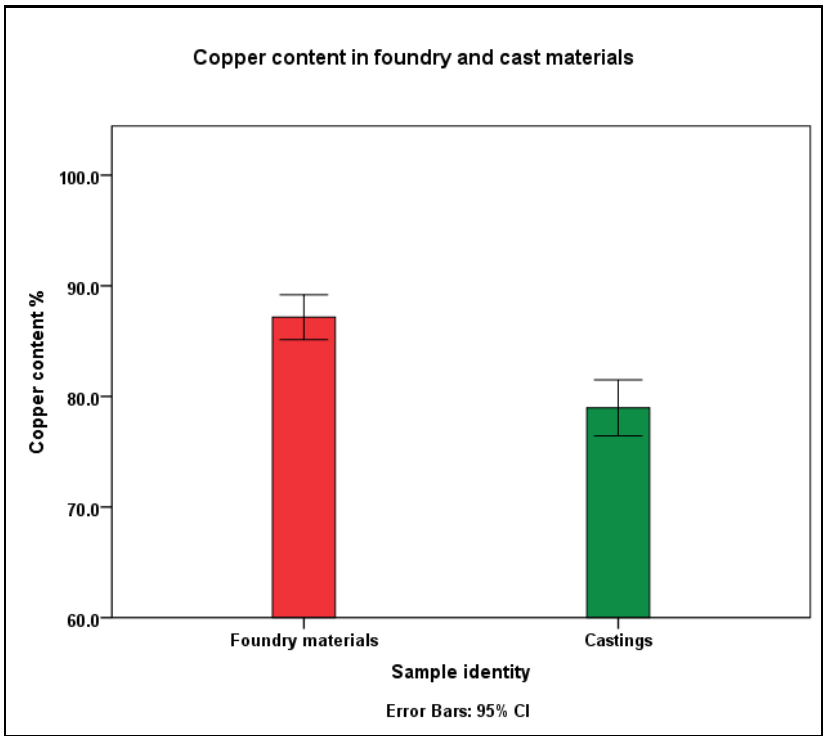


Figure4.1.2a: Copper in foundry materials and castings

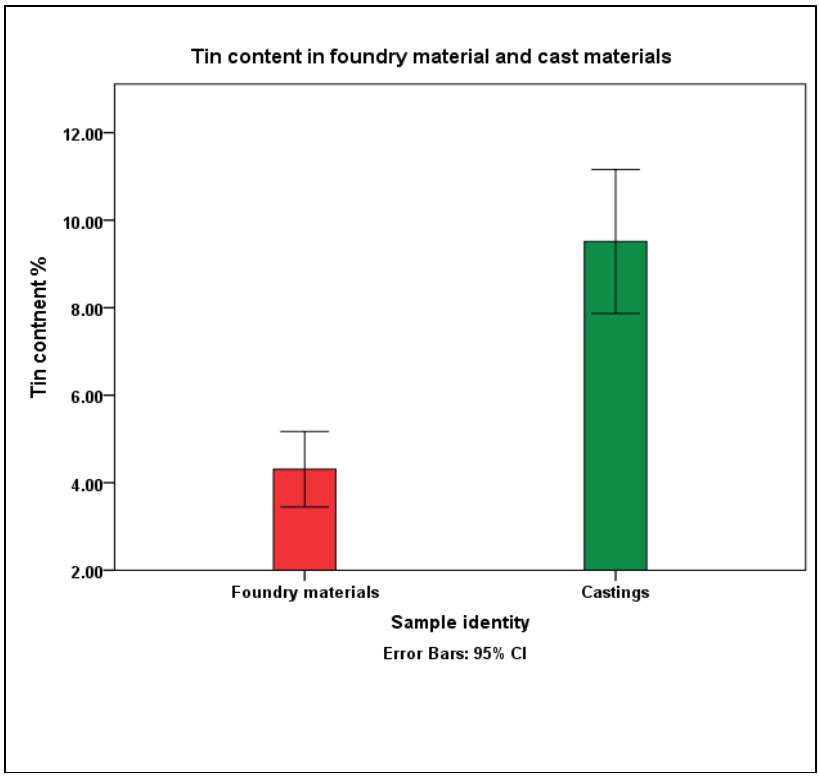


Figure4.1.2b: Tin in foundry materials and castings

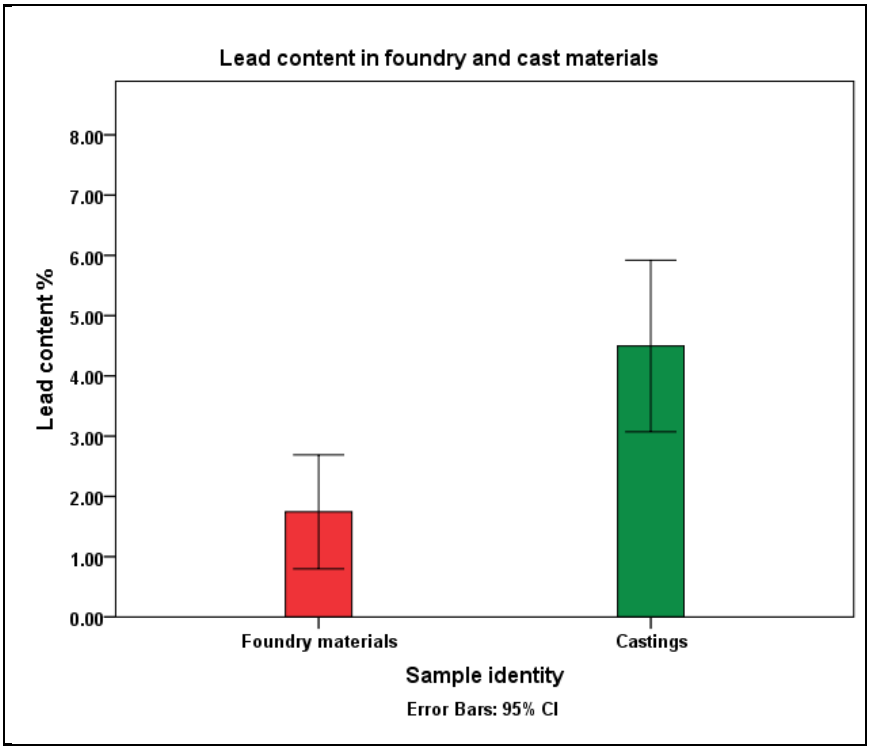


Figure4.1.2c: Lead in foundry materials and castings

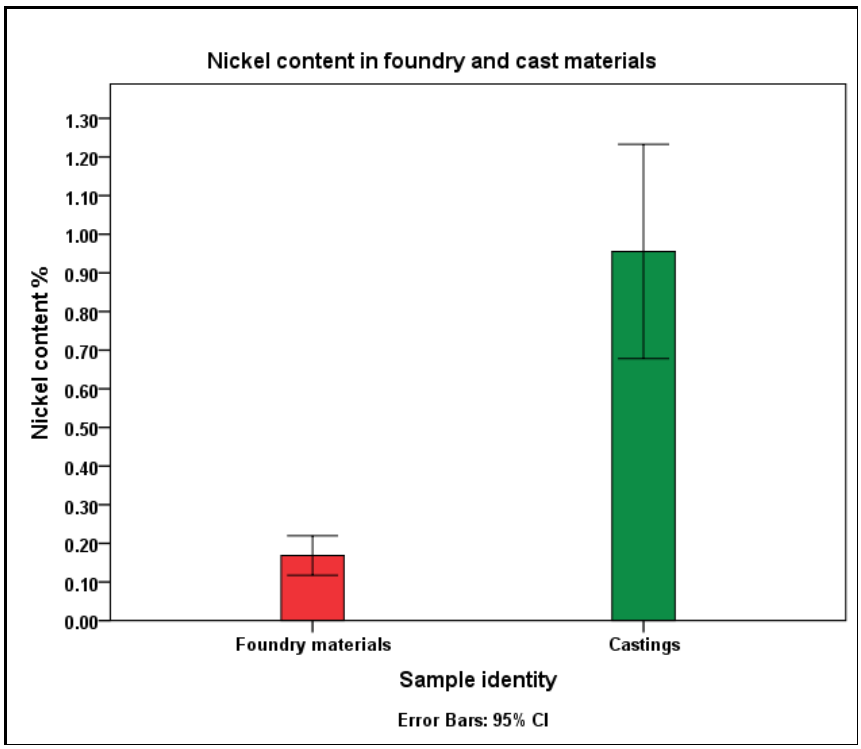


Figure4.1.2d: Nickel in foundry materials and castings

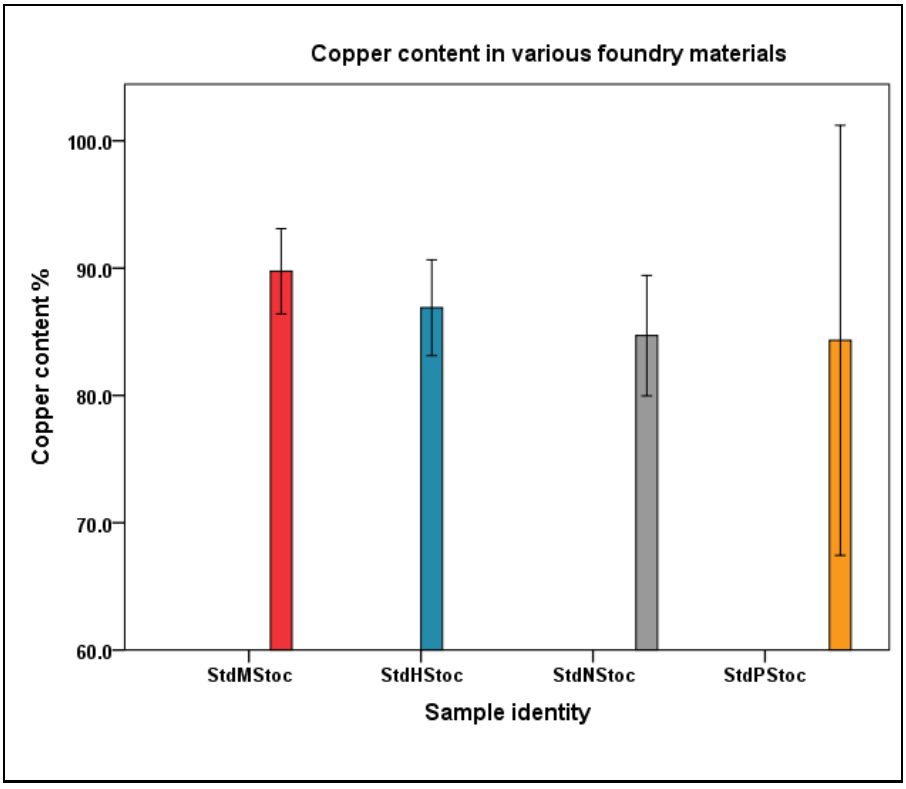


Figure4.1.2e: Comparison of copper content in various foundry materials

Although samples cast both in the laboratory and at Heroes Foundry did not show significant differences in metal contents tested in this round of trial castings with those samples collected from foundries and the various end users, the characteristic desirable bearing composition to be used or applied in such castings should reflect that given in the reference alloy, C93200, in Table 4.1.1a. This is despite the fact that copper can tolerate a wider composition range from the expected mean value than the alloying elements can as seen from the measurements in the test results and regardless of whether the bearing bronze is cast in a sand or permanent mould.

Figs.4.1.2e and 4.1.2f compared copper contents for the foundry materials and test castings. Higher copper values observed in the foundry materials than those contained in the test castings were due to lack of alloying elements in the former.

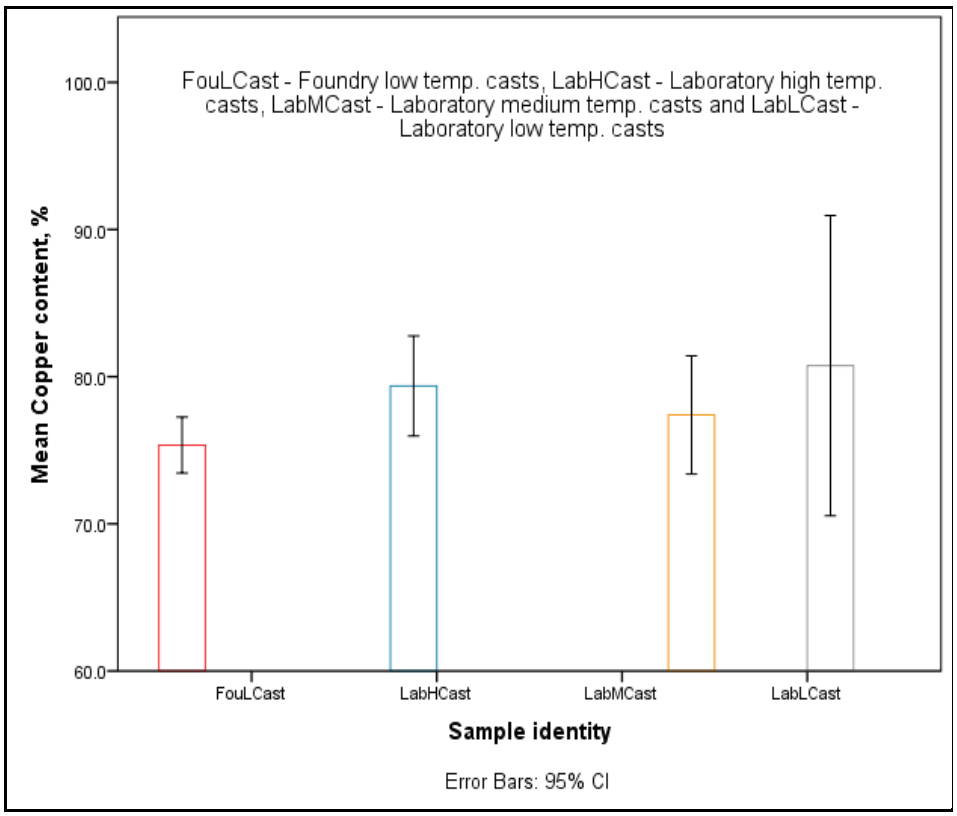


Figure4.1.2f: Comparison of copper content in various test castings

4.1.3 Hardness and friction properties in foundry materials and castings using the box plots and the t-test

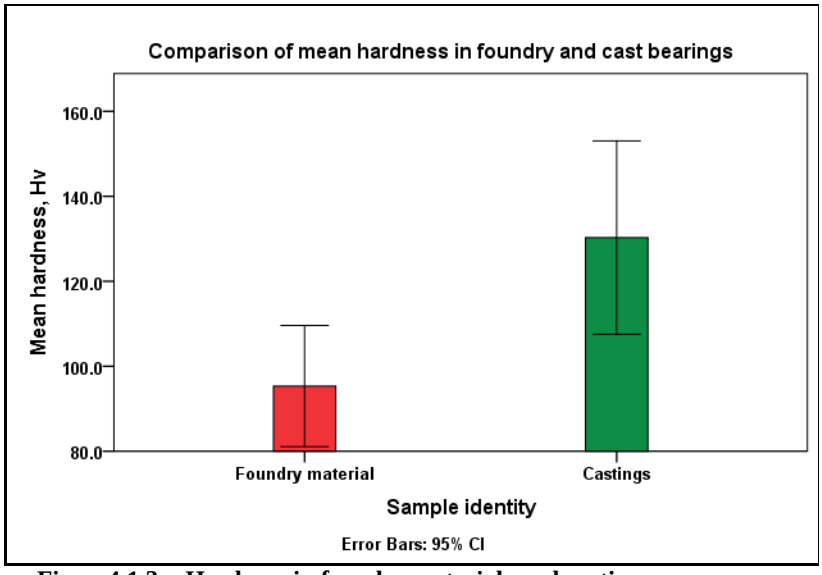


Figure4.1.3a: Hardness in foundry materials and castings

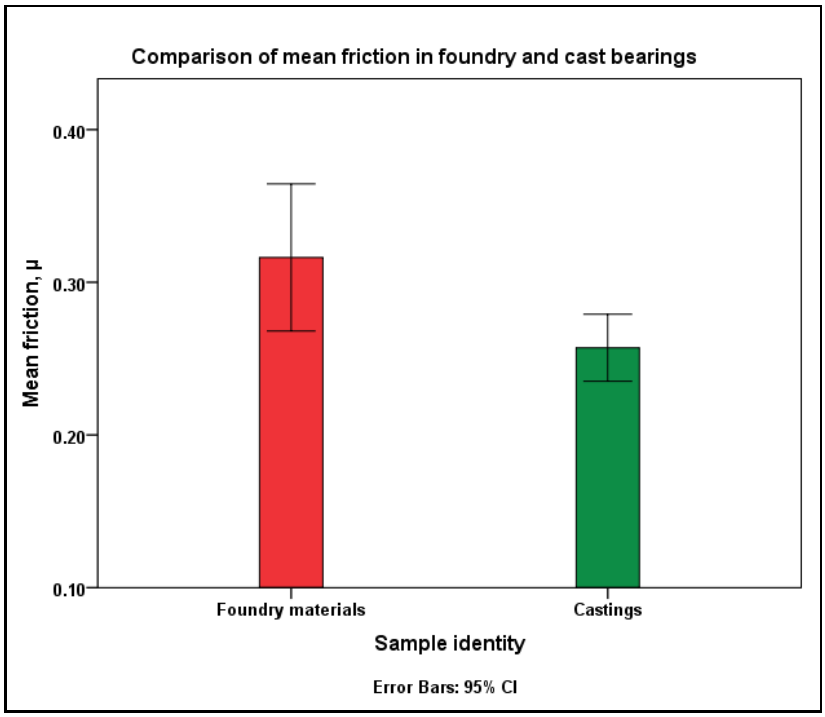


Figure4.1.3b: Friction in foundry materials and castings

The results in Figures 4.1.3a and 4.1.3b above suggest that the differences in the group means for both hardness and friction are not statistically significant. The composite hardness measurements for the foundry material samples and that of castings are compared with selected individual castings in Figure 4.1.3c below. Use of a permanent mould for casting can offer greater leverage for controlling cast microstructure by use of the cooling rate mechanism and hence change properties such as hardness. The error bars overlapped in case of group means for hardness and friction results in Figs. 4.1.3a and 4.1.3b above suggest that the difference between the two means is not statistically significant. This means that further statistical analysis between the two groups would not or was unlikely to yield any different result from that deduced by error bars already.

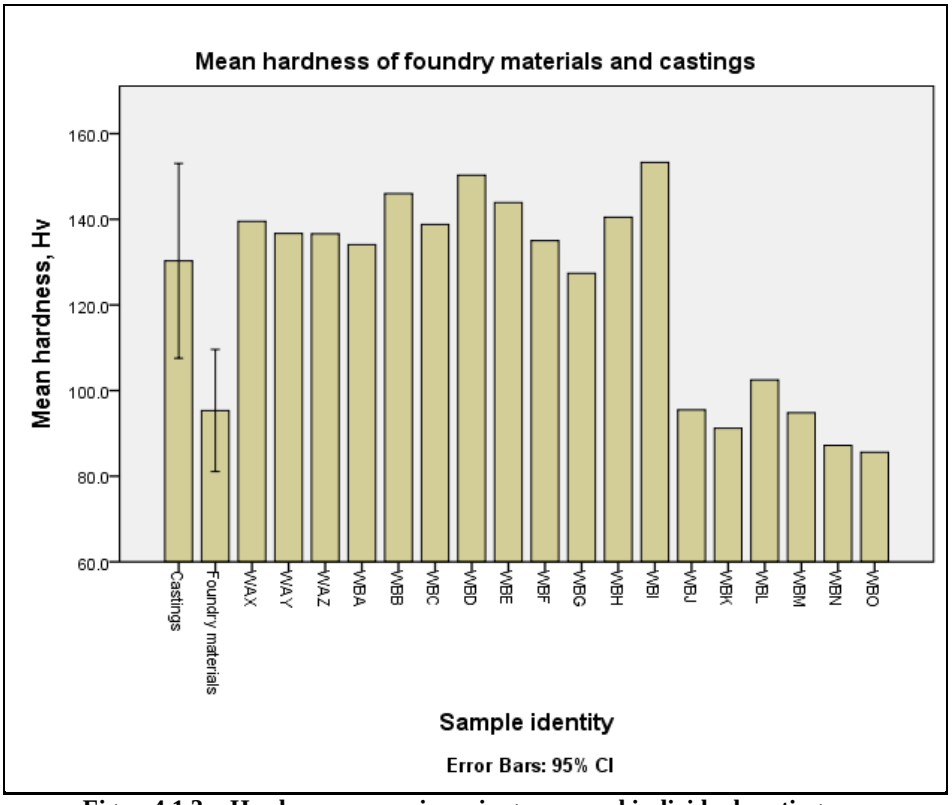


Figure4.1.3c: Hardness comparisons in groups and individual castings

It must be noted once more that bearings or materials sourced from foundries (or producers) and end users of bearings in here are referred to as 'foundry materials'. Materials or bearings that were cast at foundry and laboratory as part of experiments are referred to as 'castings'. The mean hardness value at (130.6 ± 48.1) for laboratory cast materials represented by the LHTC category was higher than the normal hardness of 85 for the target alloy C93200. Similarly the mean friction value at (0.25 ± 0.05) was higher than the expected value of 0.12. This particular category was cast at 1150 degrees Celsius.

These were statistically significant differences for hardness (45.6 (95% CI, 21.7 to 69.5), t(17) = 4.025, p = .001). For friction on the other hand the values were noted as (0.13 (95% CI, 0.10 to 0.15), t(17) = 11.576, p = .0005). The statistical summaries as evaluated using SPSS for all group samples (LMTC, LLTC, SHS, StdMStoc and SMS) are included in **Appendix 9**. Although many references indicate that there is a relationship between measured hardness and tensile strength in metallic materials and alloys, that is however restricted to wrought metals and not castings (Datsko *et al*, 2001).

4.1.4 Impact of major elements on hardness and friction properties in foundry materials and castings

Figures 4.1.4*a* to 4.1.4*p* show the impacts of major elements copper, tin, lead and nickel on the key properties of hardness and friction. In the foundry bronze bearing materials, the hardness property appeared to increase with a rise in contents of all added elements. Literature on strengthening mechanisms in metals (Bhat and Arunachalam, 1980) suggests that the more of a base element present in an alloy at the expense of strengthening elements, the less will be the hardening effect in the casting. This is based

on the understanding that anything that impedes the free motion or generation of dislocations will strengthen the material. The apparent rise in hardness (hardness-ductility ratios not checked though in tested samples) with increasing element content may be attributed to other processing or operational factors at foundries where the components were cast. The largest correlation of element content with hardness was seen for copper at R= 0.26 (Fig. 4.1.4*a*) with the lowest for tin at R= 0.01.

With the exception of copper rich materials, all the other required elements of tin, lead and nickel were not controlled at the foundries to meet compliance needs as may be demanded. In the case of laboratory cast materials and where compositions of castings were controlled, the impacts of the elements on the key properties of hardness and friction seemed to agree with expectations. An increase in the copper content resulted in a sharp decline in the hardness at R= -0.62 (Fig.4.1.4*b*) while tin showed the opposite effect on the same property at R= 0.77 (Fig.4.1.4*f*). Copper and tin had, on the other hand, showed the opposite effects on friction with respect only to the test cast samples giving R values of -0.01 (Fig.4.1.4*d*) and 0.30 (Fig.4.1.4*h*).

Copper and tin at increased contents both showed similar declining trends with respect to friction in the standard and test cast materials with R values of -0.20 (Fig.4.1.4*c*) and -0.12 (Fig.4.1.4*g*) respectively. Lead and nickel showed negative and positive correlations on hardness in the test castings at R= -0.36 (Fig.4.1.4*j*) and R= 0.44 (Fig.4.1.4*n*) respectively as would be expected. Both elements of lead and nickel on the other hand registered a decline in friction for the test castings at R= -0.48 (Fig.4.1.4*l*) and R= -0.22 (Fig.4.1.4*p*). Alloying elements and their ability to strengthen a metal alloy did not play a role whatsoever in the foundry materials examined. The apparent rise in hardness with increasing element content for foundry materials may be said to

have been more due to processing factors in the foundries concerned rather than anything else. In addition, scatter of data in the Figs. *4.1.4a to 4.1.4p* is represented by the values of R. Other than for a single case, the plots revealed that the apparent changes in the percent contents of the elements analysed had little or no impact on the properties of the materials tested.

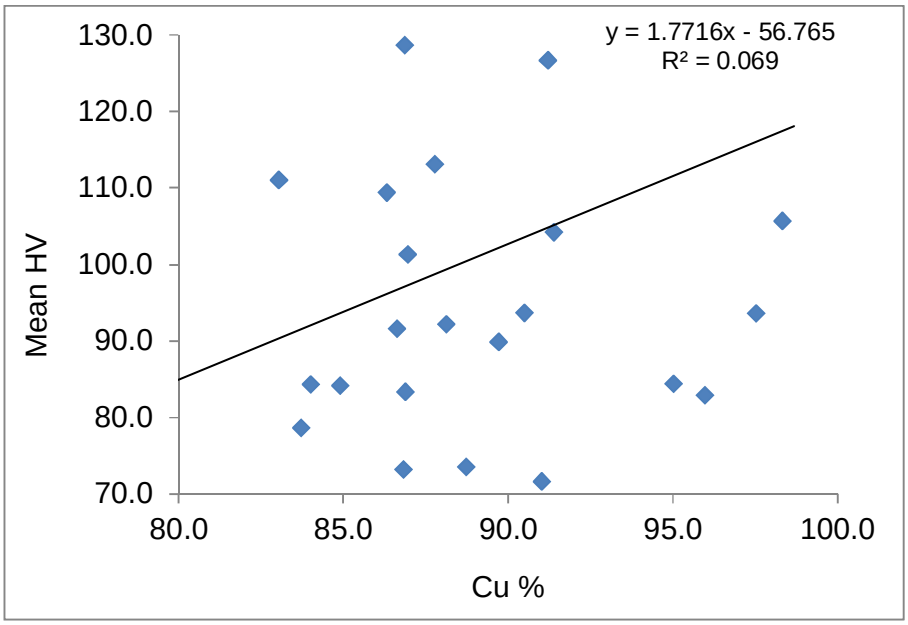


Figure4.1.4a: Impact of copper content on hardness for standard samples

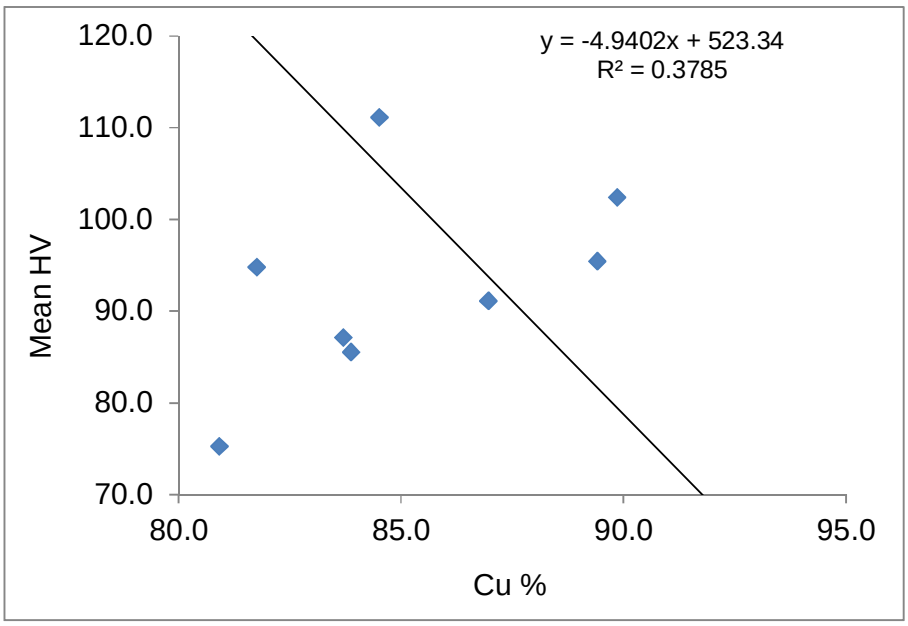


Figure4.1.4b: Impact of copper content on hardness for cast samples

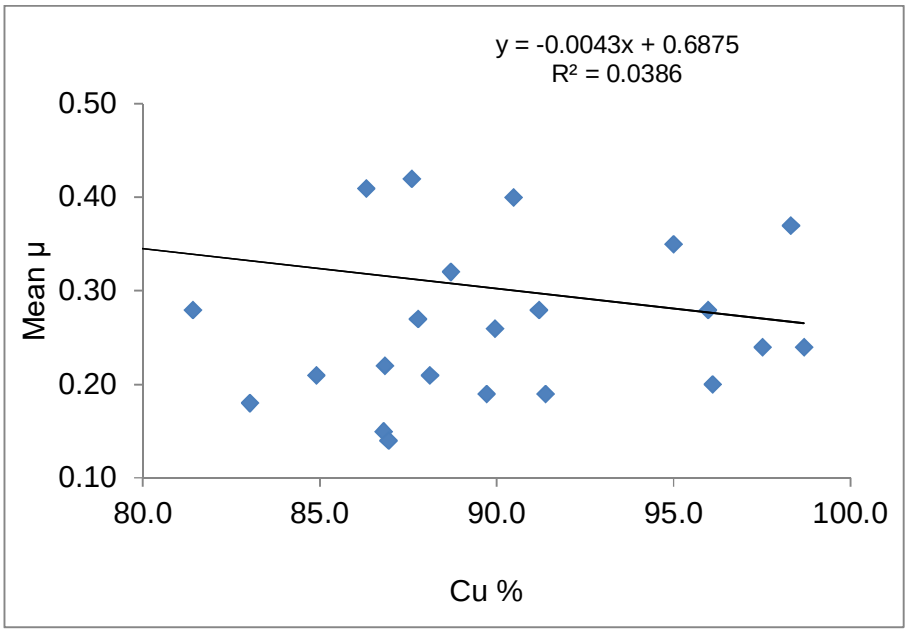


Figure4.1.4c: Impact of copper content on friction for standard samples

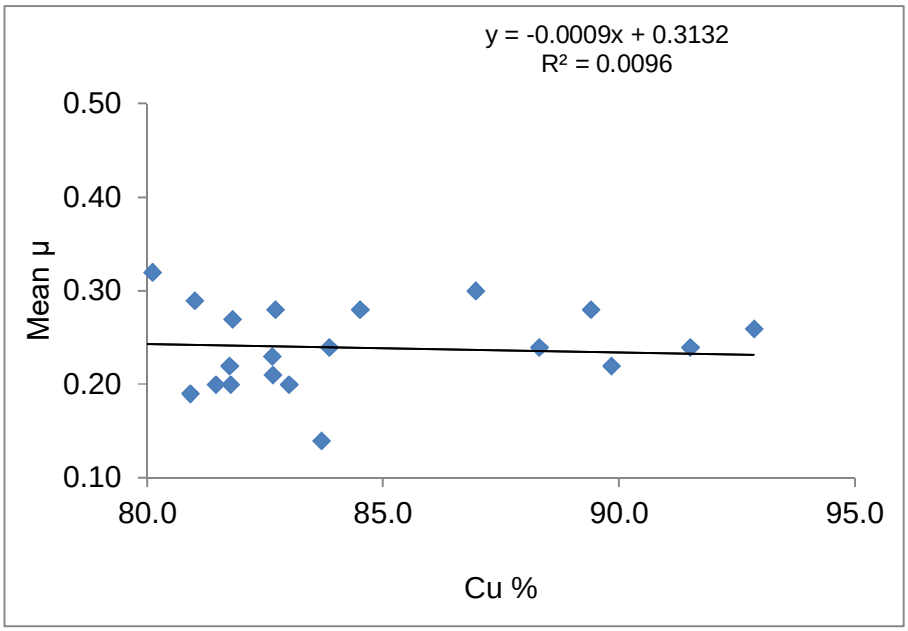


Figure4.1.4d: Impact of copper content on friction for cast samples

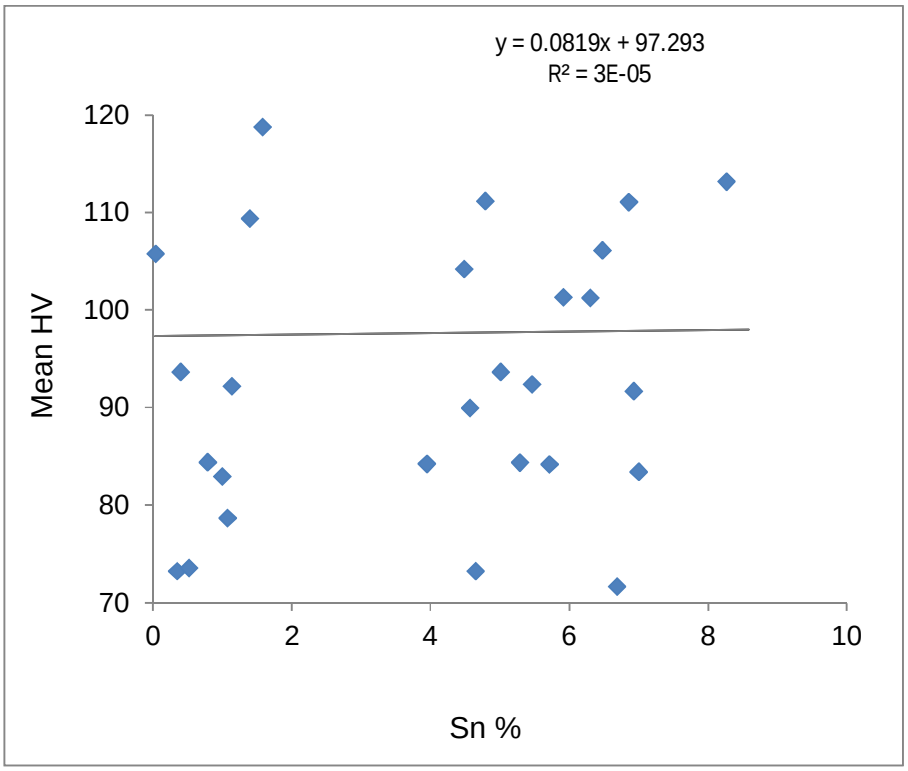


Figure4.1.4e: Impact of tin content on hardness for standard samples

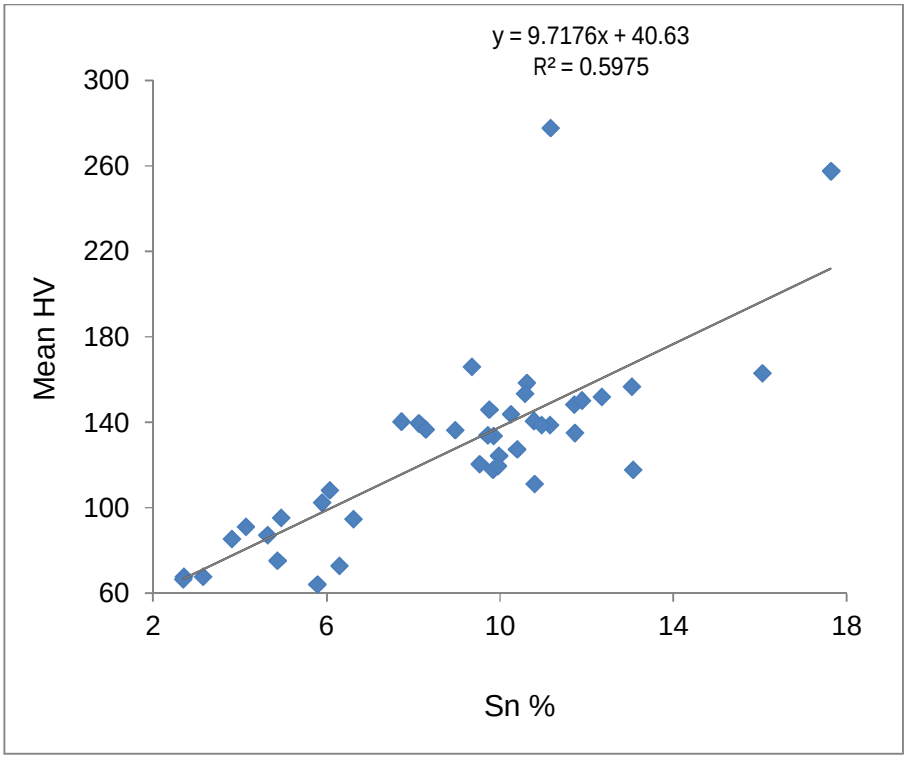


Figure4.1.4f: Impact of tin content on hardness for cast samples

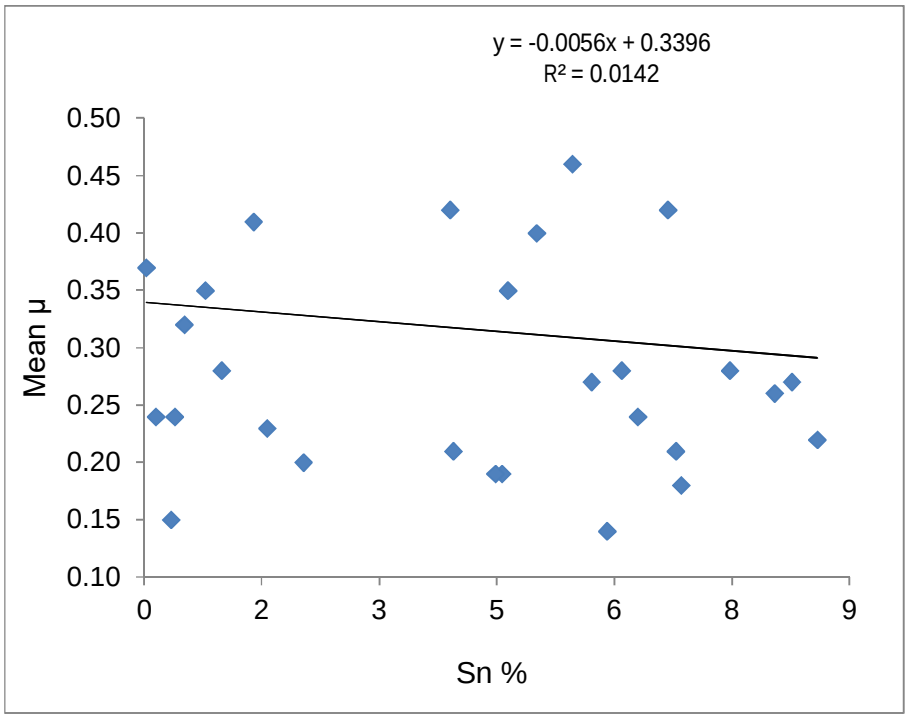


Figure4.1.4g: Impact of tin content on friction for standard ingot (machine bar) samples

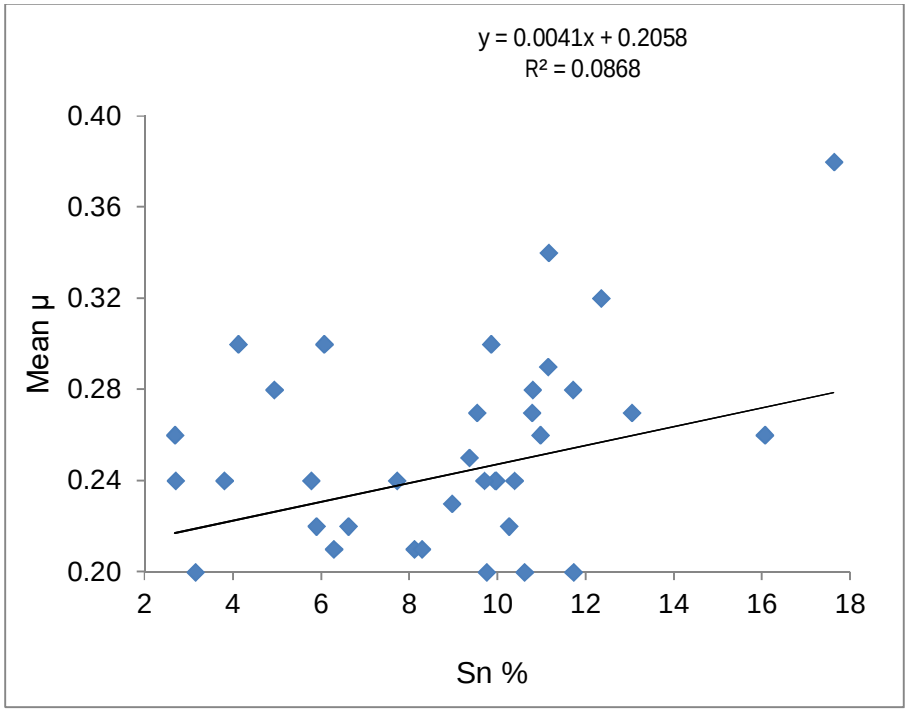


Figure4.1.4h: Impact of tin content on friction for cast samples

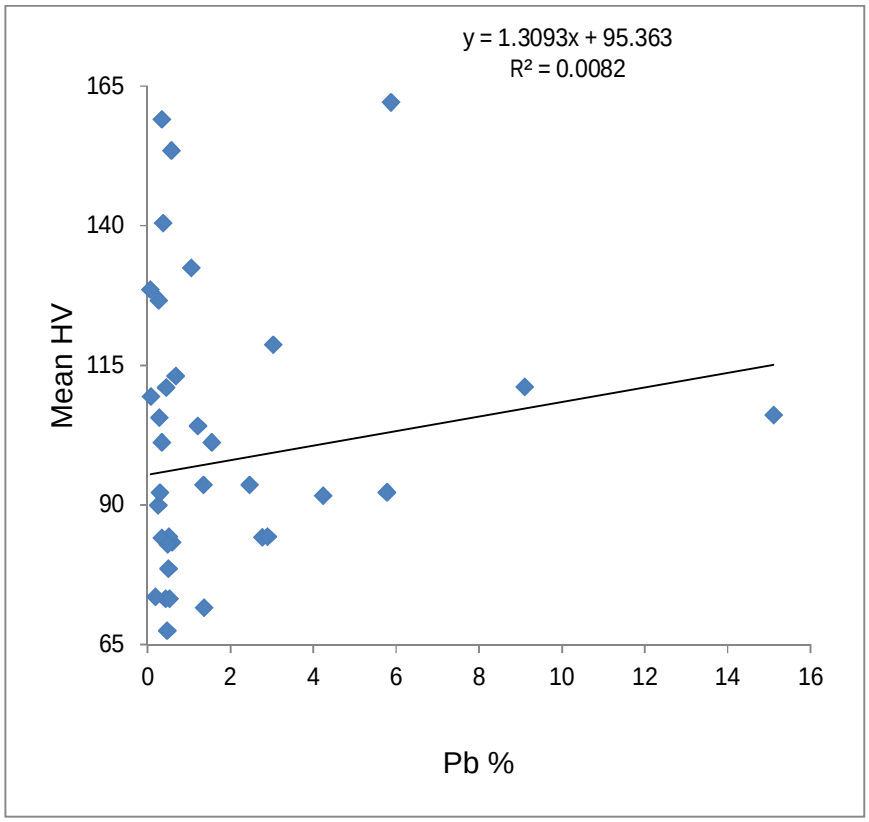


Figure4.1.4i: Impact of lead content on hardness for standard samples

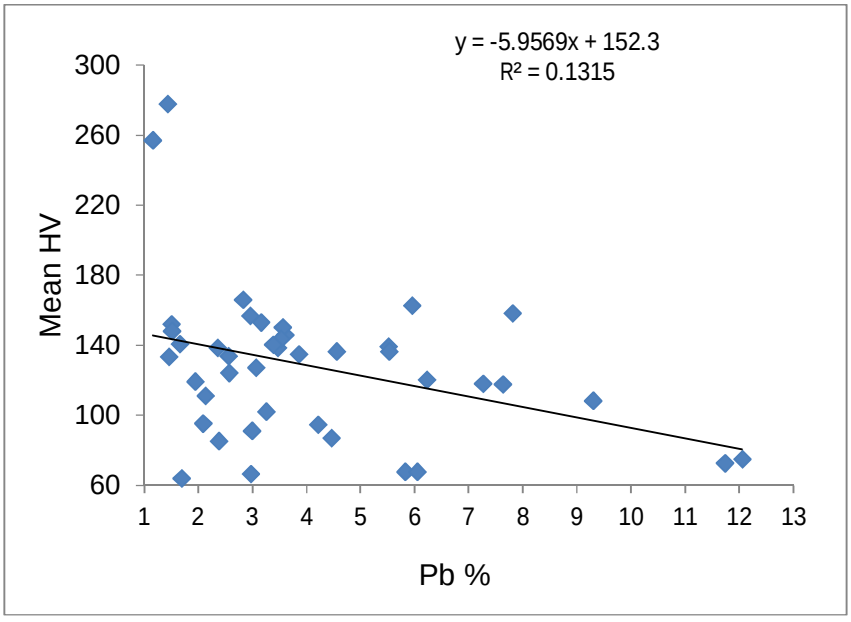


Figure4.1.4j: Impact of lead content on hardness for cast samples

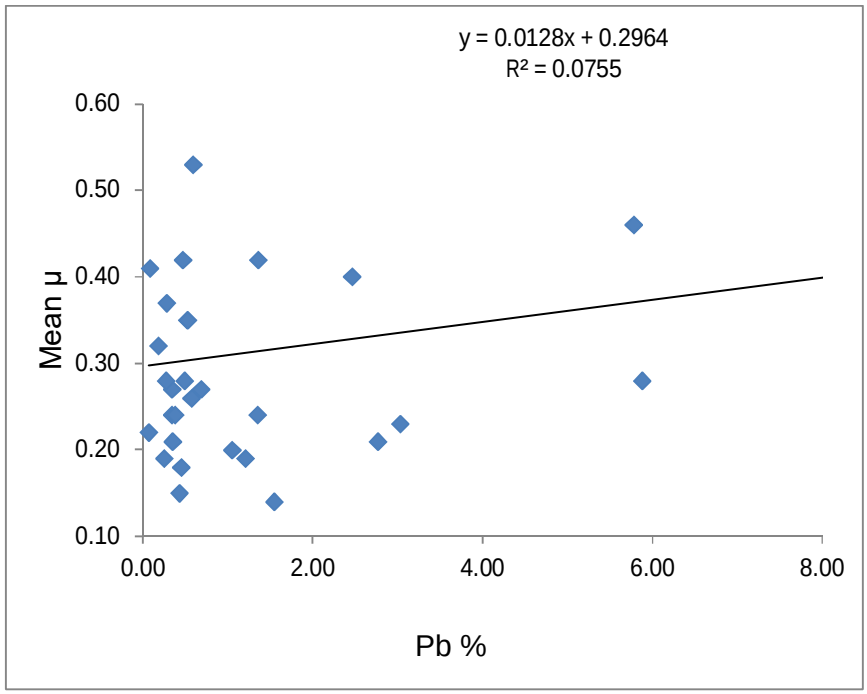


Figure4.1.4k: Impact of lead content on friction for standard samples

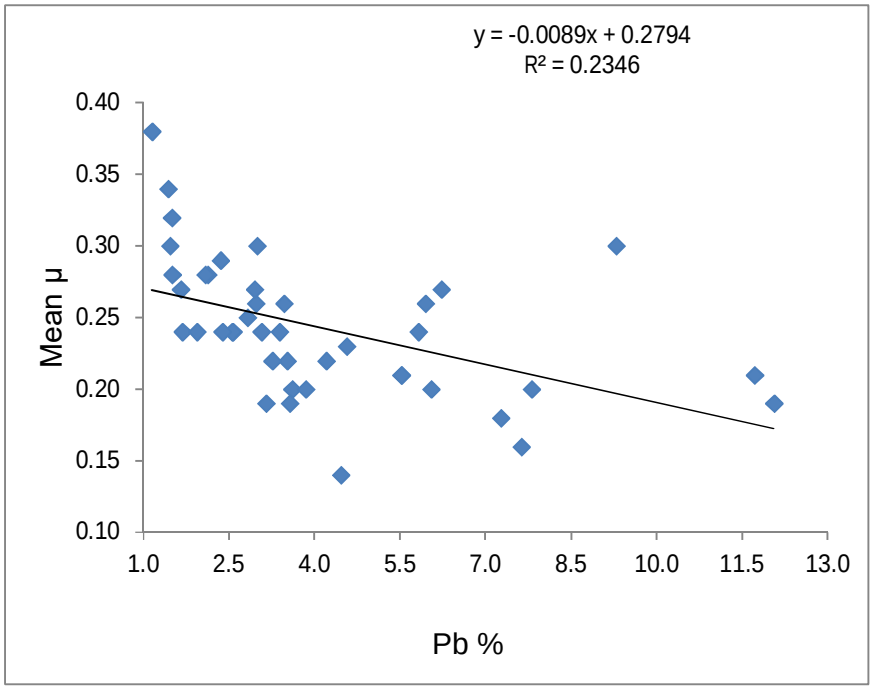


Figure4.1.4l: Impact of lead content on friction for cast samples

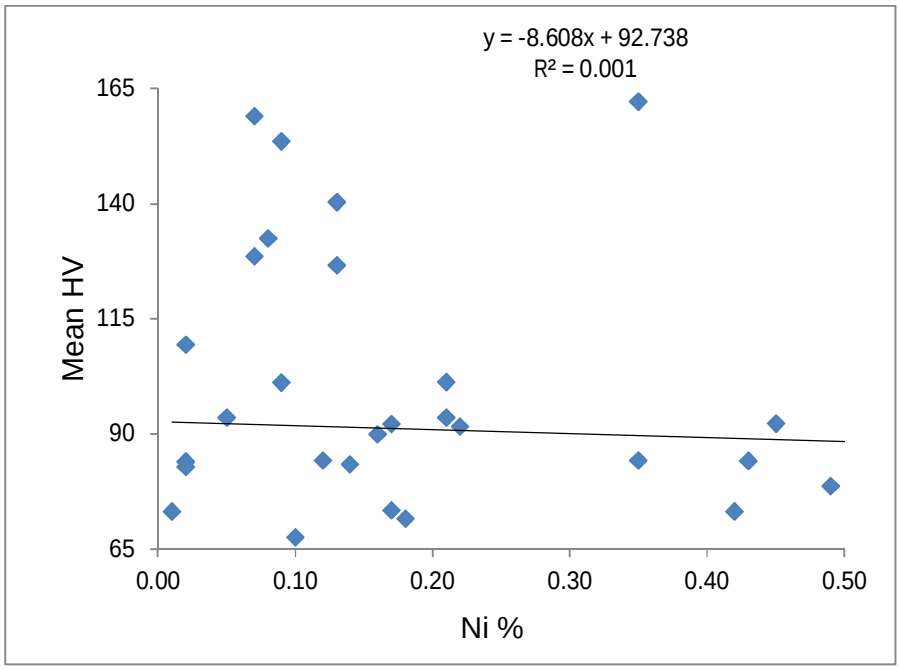


Figure4.1.4m: Impact of nickel content on hardness for standard samples

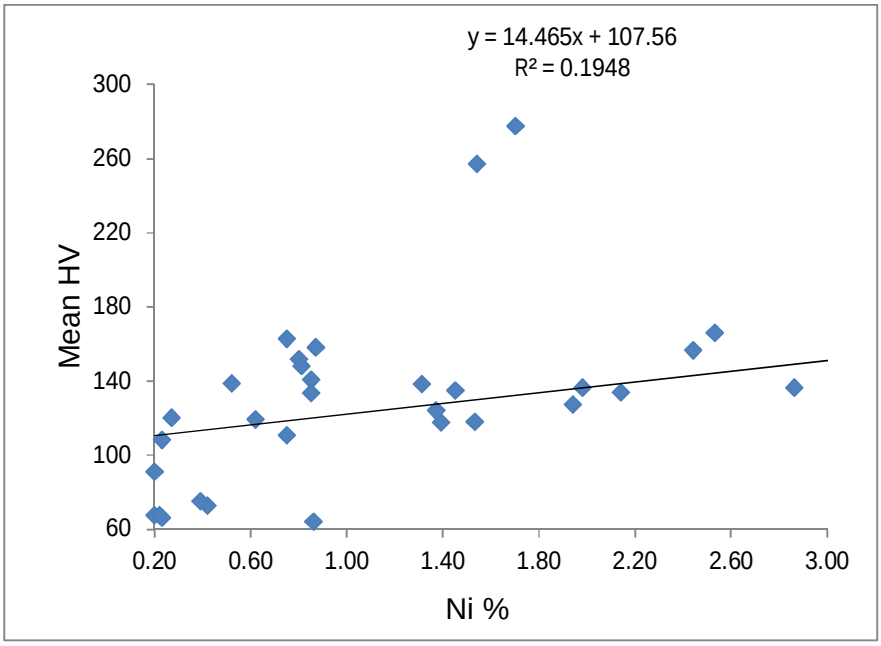


Figure4.1.4n: Impact of nickel content on hardness for cast samples

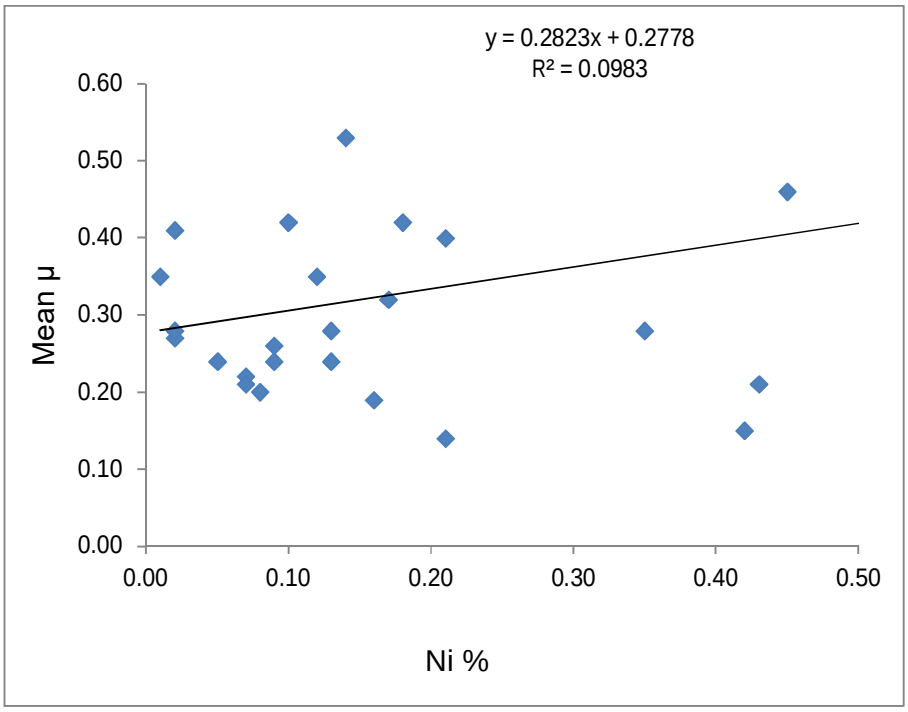


Figure4.1.4o: Impact of nickel content on friction for standard samples

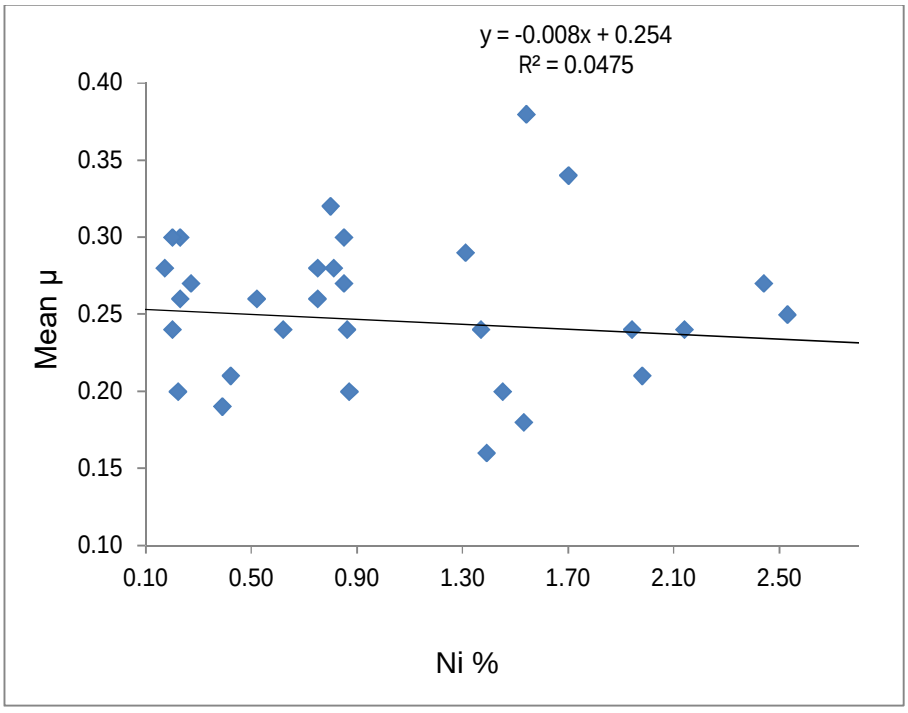


Figure4.1.4p: Impact of nickel content on friction for cast samples

4.1.5 Influence of microstructure on properties in foundry materials and castings

The optical micrographs of microstructures shown in Figs. 4.1.5*a* to 4.1.5*h* for foundry materials and 4.1.5*i* to 4.1.5*p* for castings. Although all the samples generally showed the expected copper rich alpha (α) solid solution as matrix phase with tin rich second phase appearing mostly as lighter brown areas than neighbouring darker ones as seen in Figs. 4.1.5a to 4.1.5c. Foundry materials had coarser grain structures and showed some significant levels of porosity in comparison with the castings. Large grain structures would be expected in sand cast bronzes but the use of a permanent mould provides an opportunity to manipulate cast structure and hence siginificantly influence final properties. Although casting conditions for the collected foundry materials and the castings produced in the laboratory foundry may not be compared directly, the impact of close control in the case of the latter group of items on microstructures was obvious.

Laboratory cast materials were finer in grain structures than the foundry materials. Manual representation of the micrograph magnification in comparison with use of electronic scale bar was more reliable on the optical instruments used for the purpose. The presence of tin, lead and nickel in the foundry materials with the exception of a few samples was generally by chance, accidental or a carry-over from other materials. Numerous other elements (possibly tramp) or phases that could not be resolved or determined made up the composition of the foundry materials. The structures of the castings on the other hand showed that it was possible to eliminate inconsistencies in composition and structure and have a successful product at the small foundry level. To achieve that outcome in the foundry, specific practices and steps must be adhered to consistently.

It must be noted that if scrap remains the only or major resource input for SURFs, elimination of tramp elements in the final bearing products will be a big challenge. The economics of keeping the tramp elements to acceptable levels that are not harmful to properties of final products must be investigated. For instance, the element phosphorus which remains as residual after degassing copper alloys, should be kept below 0.05% beyond which it affects the microstructure by porosity formation.

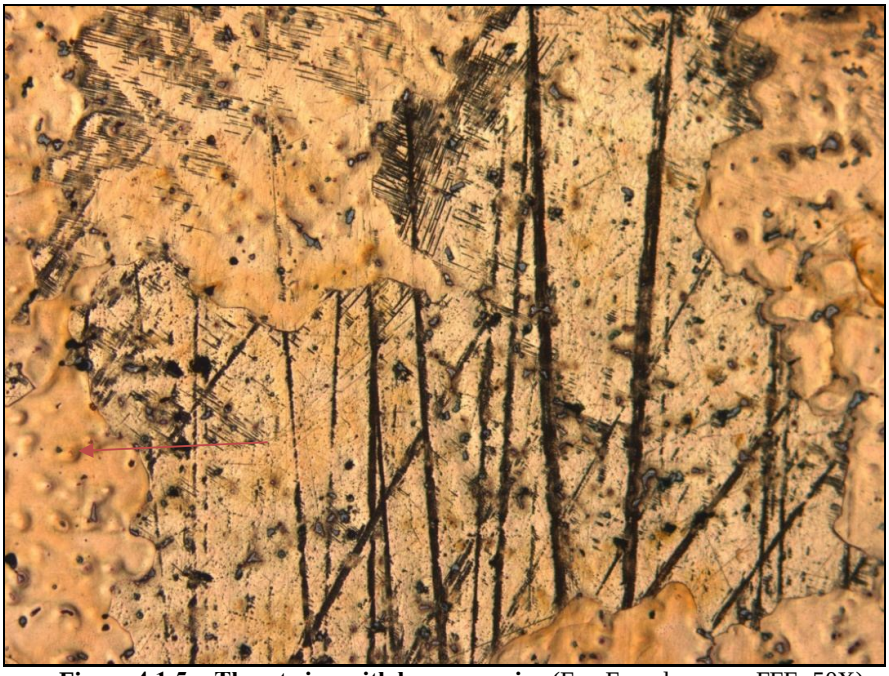


Figure 4.1.5a: Thrust ring with large α grains (Fox Foundry scrap FFE, 50X)

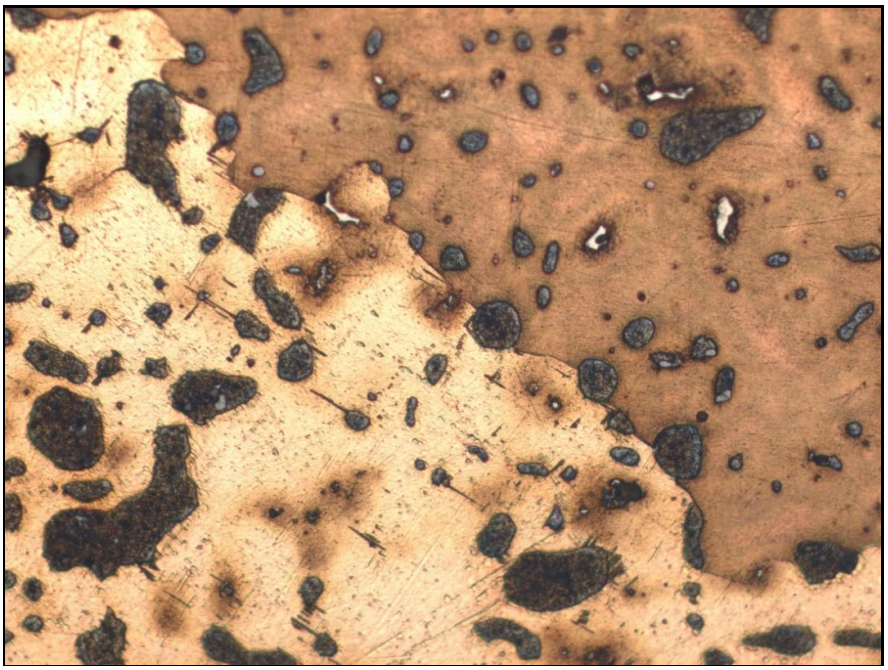


Figure 4.1.5b: Secondary crusher liner (Konkola Copper Mines KCA, 100X)

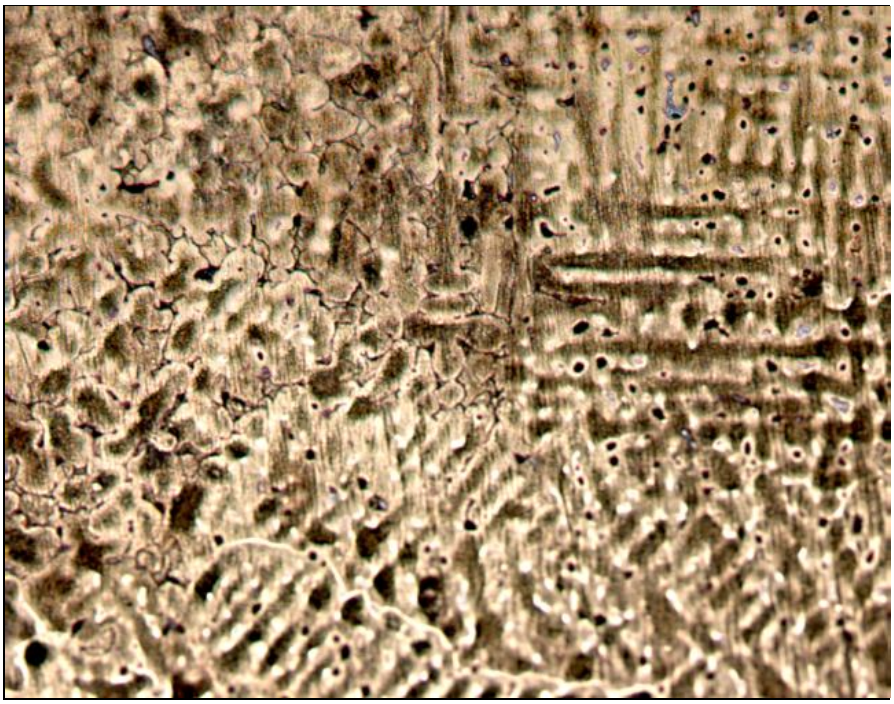


Figure 4.1.5c: Used bearing (Fox Foundry scrap FFG, 100X)

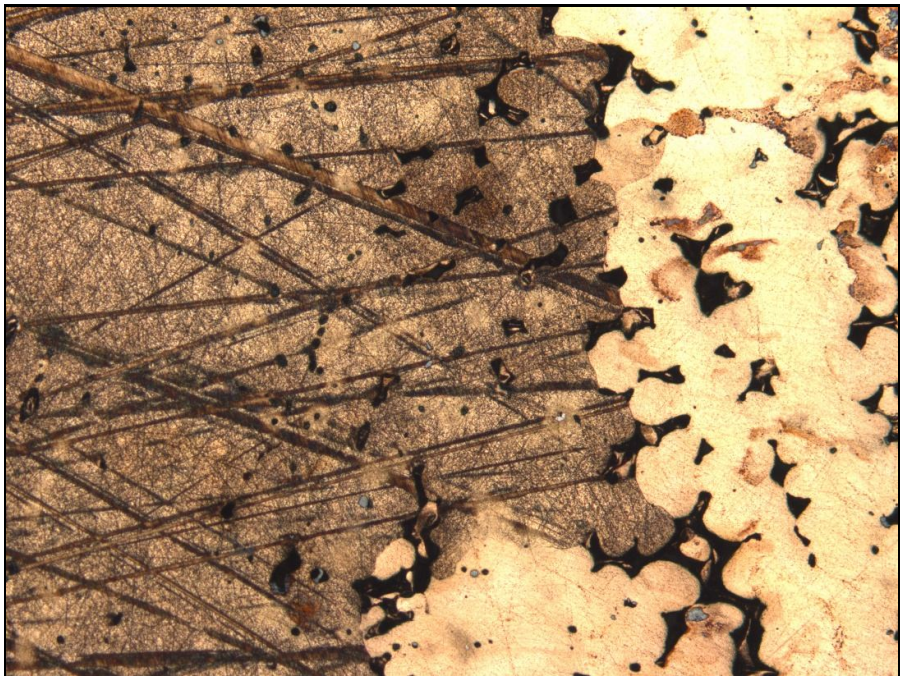


Figure 4.1.5d: Cast billet for sale (Fox Foundry FFA, 50X)

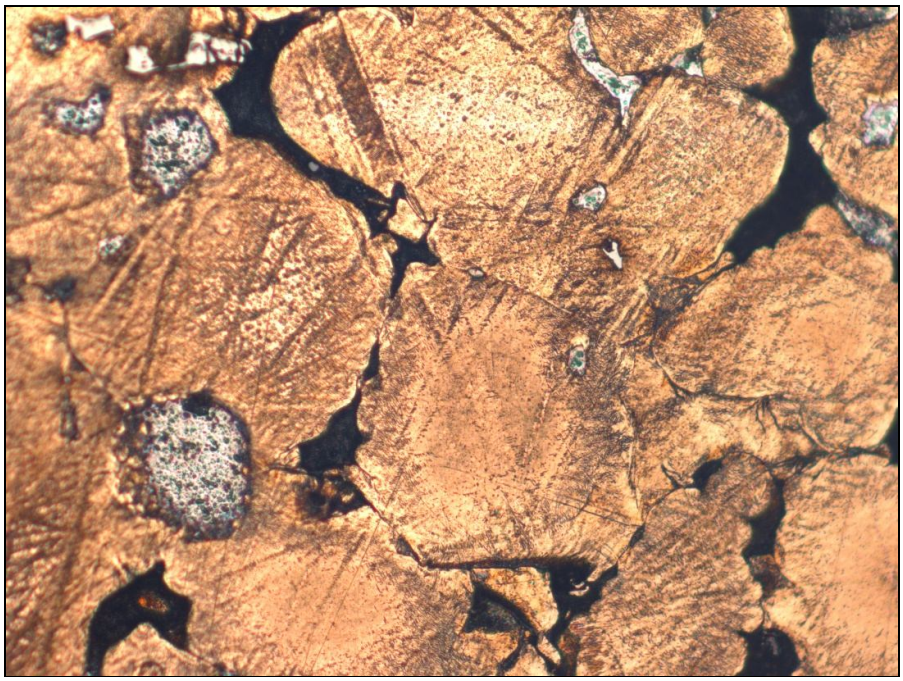


Figure 4.1.5e: Crusher shaft barrel bearing (Mopani Copper MCG, 200X)

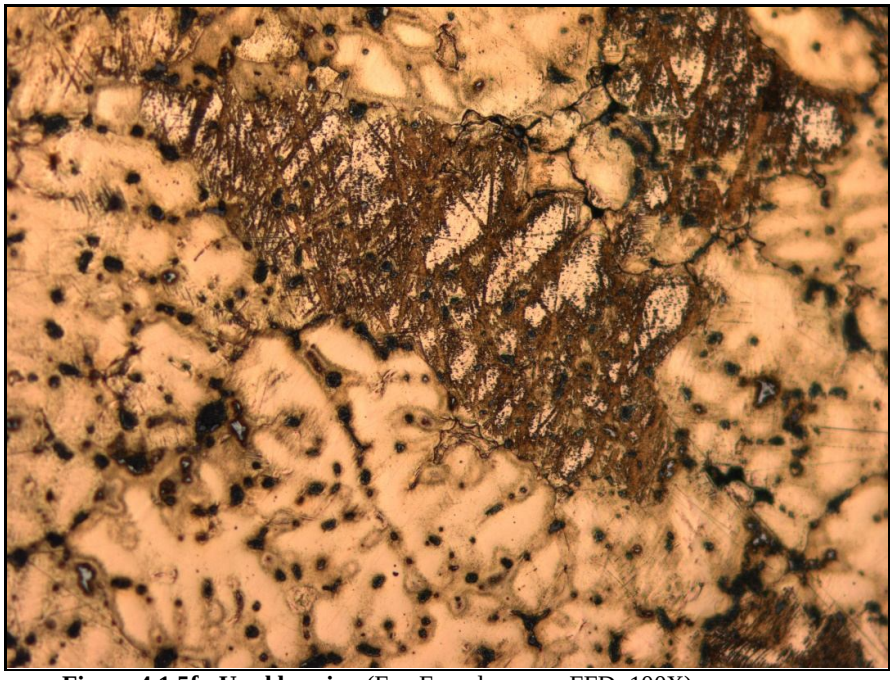


Figure 4.1.5f: Used bearing (Fox Foundry scrap FFD, 100X)

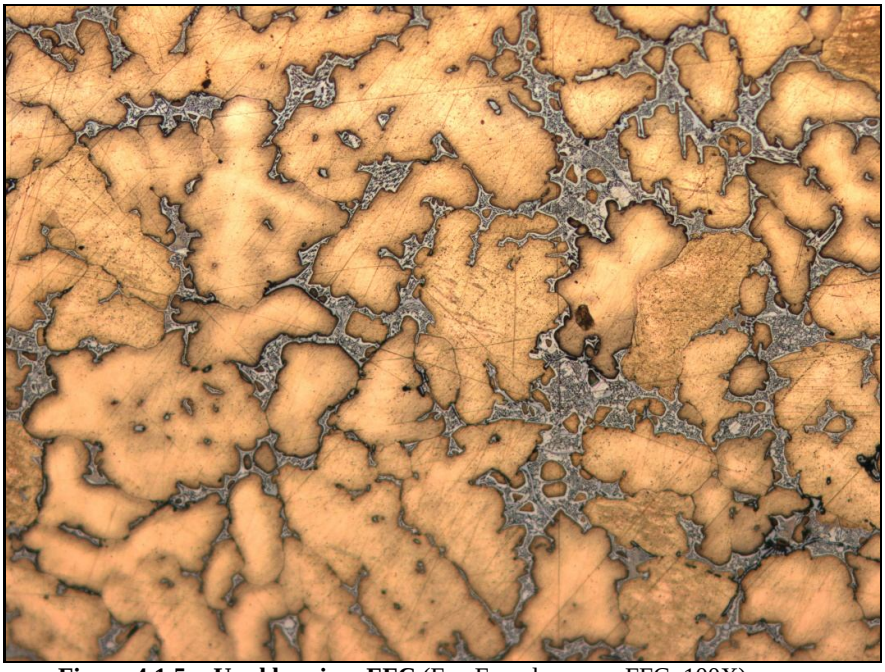


Figure 4.1.5g: Used bearing, FFC (Fox Foundry scrap FFC, 100X)



Figure 4.1.5h: Used bearing (Fox Foundry scrap FFJ, 50X)



Figure 4.1.5i: Cast sample (Univ. of Joburg WAX, 100X)



Figure 4.1.5j: Cast sample, WAY (Univ. of Joburg WAY, 100X)

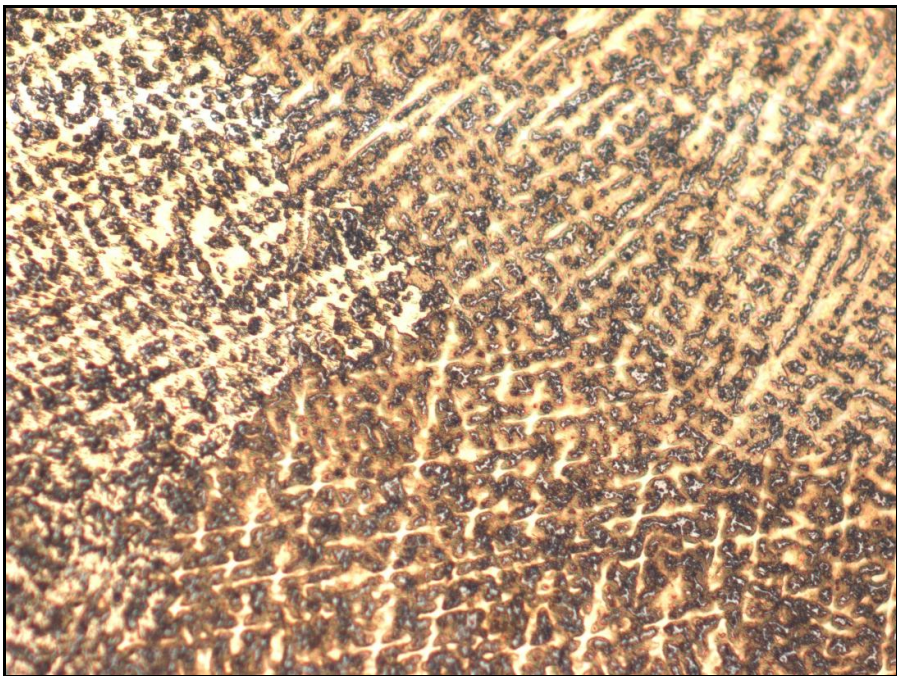


Figure 4.1.5k: Cast sample (Univ. of Joburg WBA, 200X)

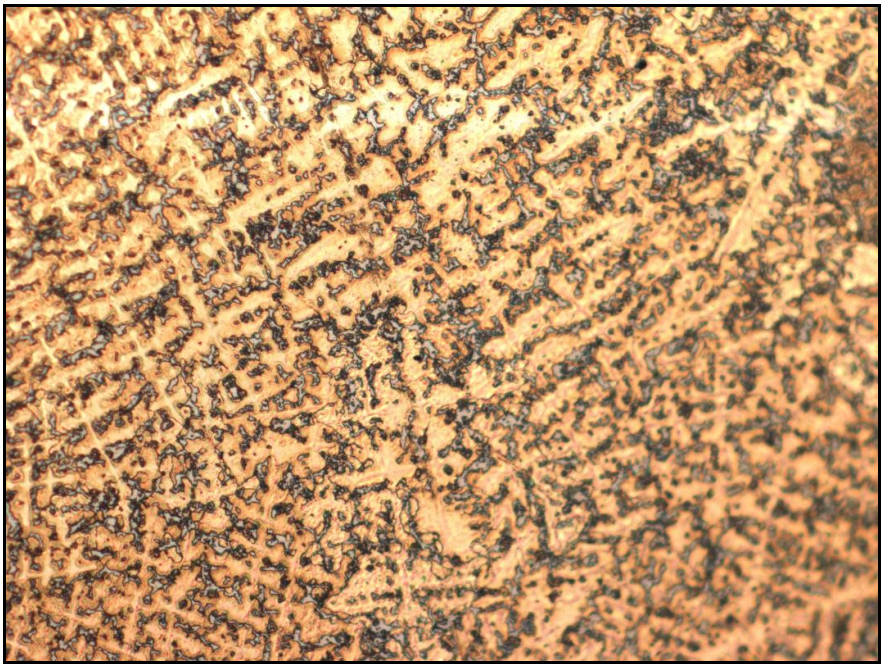


Figure 4.1.5l: Cast sample (Univ. of Joburg WBE, 200X)

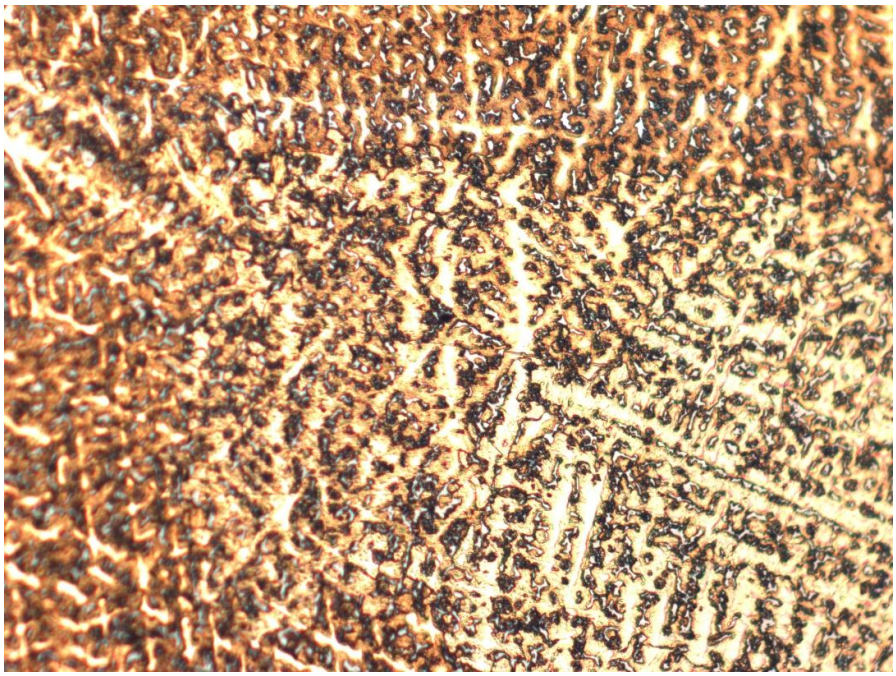


Figure 4.1.5m: Cast sample, WBH (Univ. of Joburg WBH, 200X)

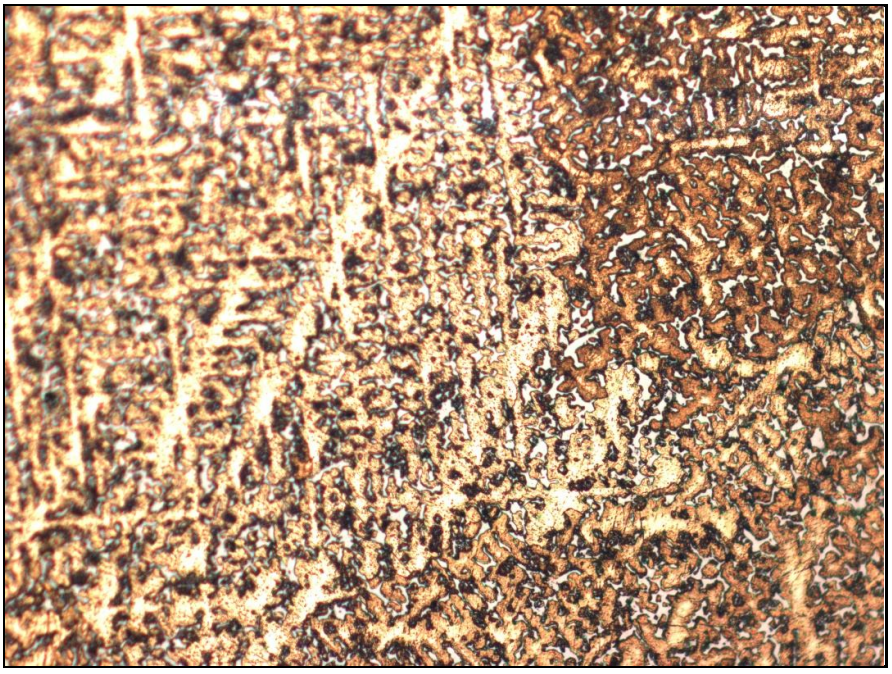


Figure 4.1.5n: Cast sample (Univ. of Joburg WBI, 200X)

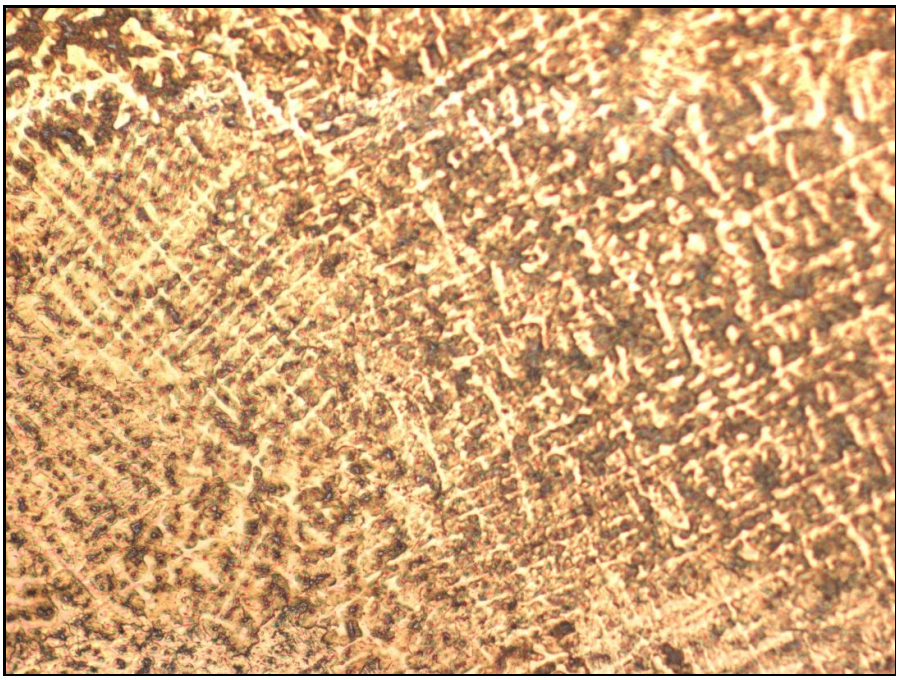


Figure 4.1.5o: Cast sample (Univ. of Joburg WBL, 200X)

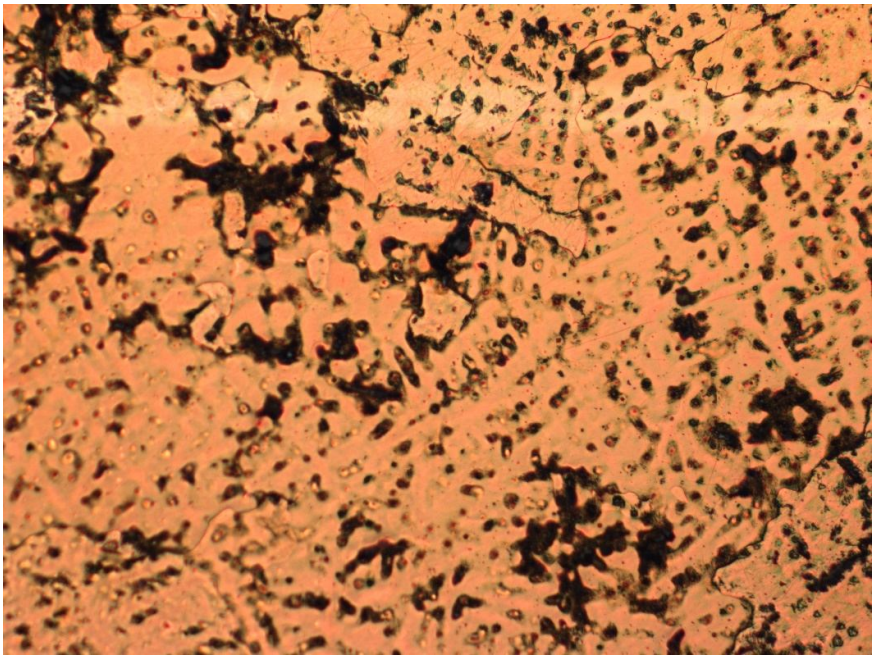


Figure 4.1.5p: Cast sample (Univ. of Joburg WBO, 200X)

4.1.6 Friction variations over test distance in some foundry materials and castings

Surface friction tests conducted using parameters referred to in *Section 3.1.1* yielded results displayed in figures 4.1.6*a*, 4.1.6*b* and 4.1.6*c* for some samples. The plots show friction variation over the test distance of 100 metres for individual samples. In one case a smoothing effect plot for sample HFC (power HFC) is included to show its mean friction variation over the test distance. The trend in the change of friction or coefficient of friction over the test distance showed a gradual rise as a result of work hardening of the test material. More than eighty (80) samples were available for testing. Friction values were confirmed for seventy four (74) of them as shown in **Appendix 8**. In general the friction performance of the castings were not different from those that were foundry materials (or produced by foundries where samples were collected). The friction results in this case suggest that performance of bearings cast in permanent moulds would not be different from those that are sand cast.

Permanent mould casting at a local foundry level without any form of automation has advantages of near net finish and can reduce costs considerably. Provision of taper in all parts of the permanent mould is not necessary especially where sufficient parting lines have been incorporated. Friction variations for test cast samples HFC and HFD in comparison with foundry materials FFA and FFL in one instance and NFB and HFA in another. Friction values for the test castings were displaying in a close band and sandwiched between those of foundry materials. Other test cast samples of WAA and WAB displayed a similar pattern over the same friction distance when contrasted with foundry materials FFC and FOR. It is therefore feasible that with a closely controlled composition and structure of final castings, small foundries can succeed in producing acceptable quality bronze bearings that show some consistency in properties.

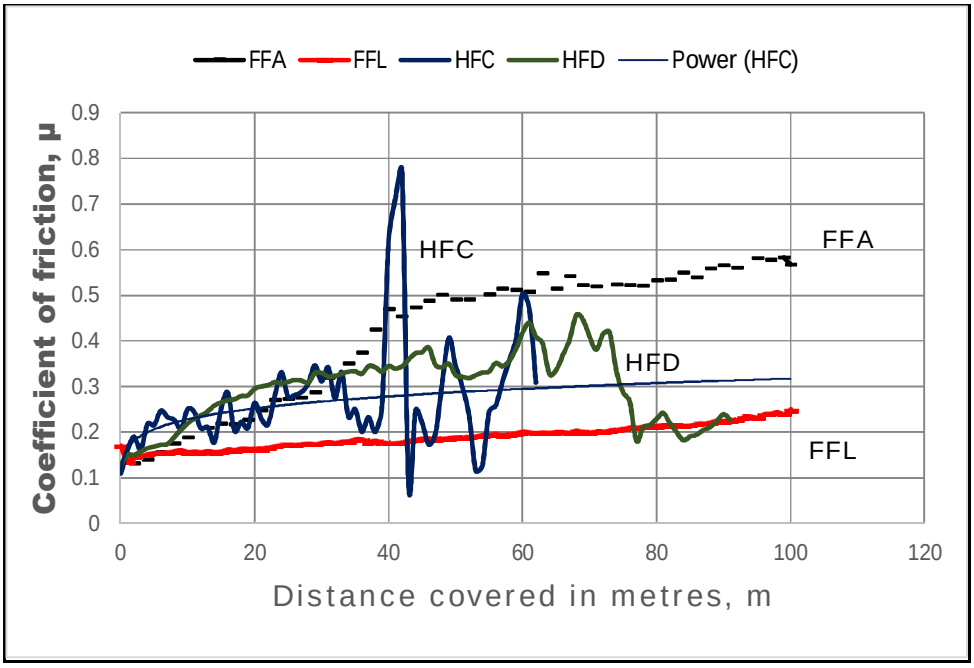


Figure 4.1.6a: Friction comparisons of foundry billets (FFA and FFL) and experimental casts

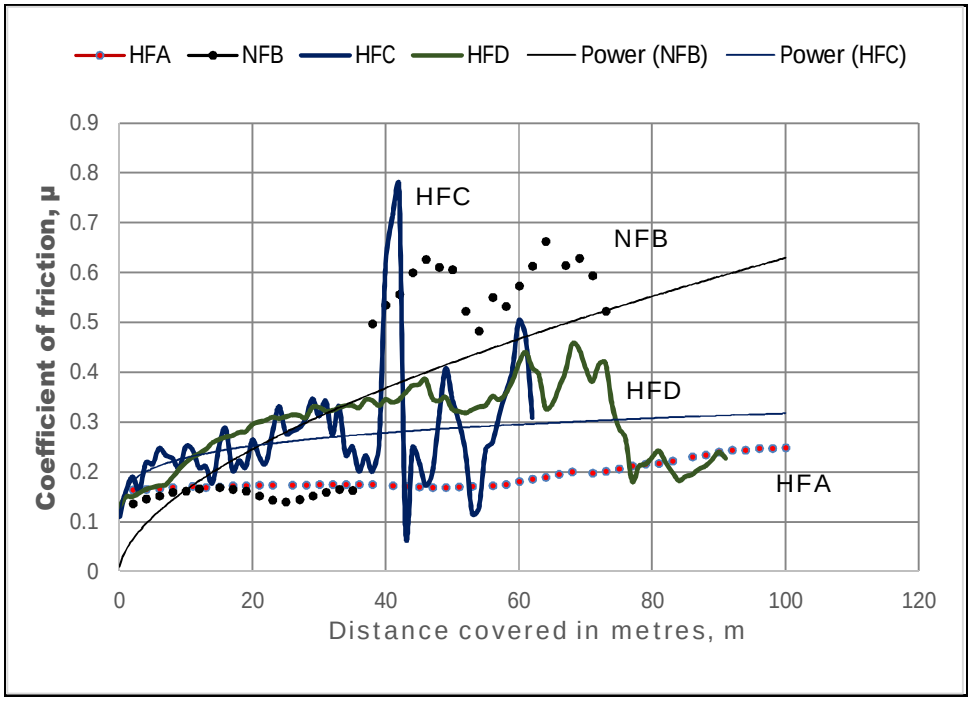


Figure 4.1.6b: Friction comparisons of foundry billets (NFB and HFA) and experimental casts

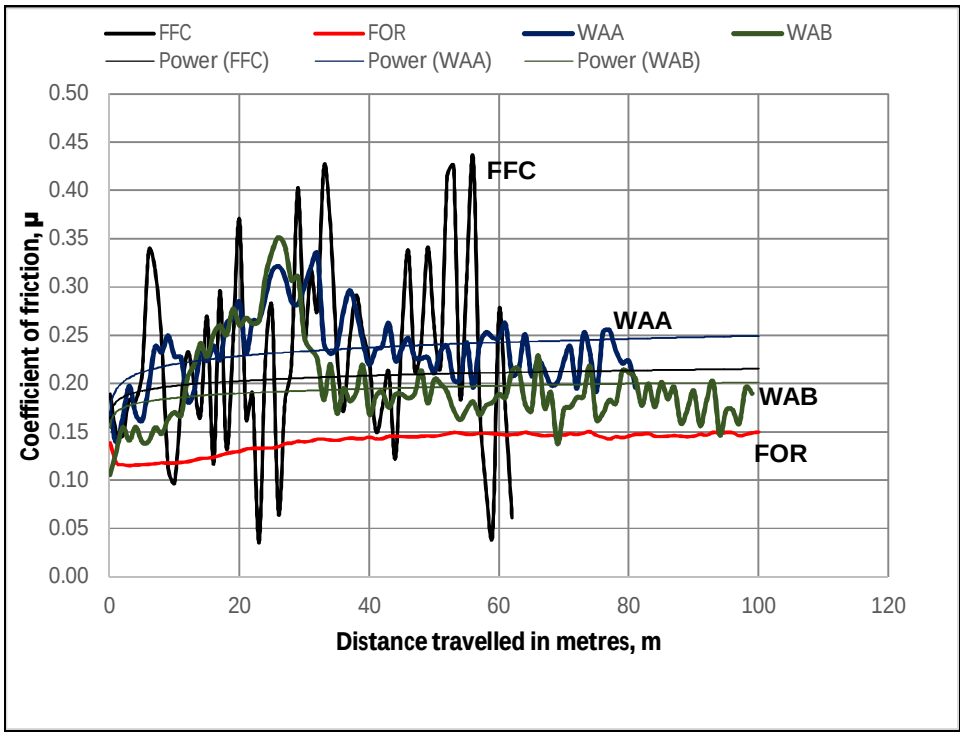


Figure4.1.6c: Friction comparisons of foundry billets (FFC and FOR) and experimental casts

The fluctuating or frequent peaks and lows for friction over the test distance for the samples HFC, HFD, NFB, FFC and WAA was an indicator of lack of compositional and structural and homogeneity. The presence of significant porosity in the foundry material had a negative impact on their physical quality in terms of consistent mechanical properties. The power plot equivalents of the original friction curves addressed the issue of best fit from the data obtained.

4.2 Suitability of small foundries for bearing production

As stated in **Section 3.2**, the facilities visited in Zambia during the course of research used the gravity casting method. With suitable modifications of production lines, bearing bronzes can be produced using a permanent mould of the type tested at Heroes Foundry. An infusion of skills to the work force targeting understanding rather than just transfer of technology and techniques offers a much better chance of achieving desired

qualities sustainably. The suggested contents and duration of a training programme for the purpose are given in **Appendix 5**. Bronze bearing production in the suggested training programme is a significant portion of output in all cases. Other than lack of verification of cast quality in terms of chemistry and microstructure, processes and procedures used by the small foundries visited were considered by the operators adequate for bronze production. However consultations with local copper producers suggest their disssatisfaction with the performce experienced from locally produced products. Conseqently the application of locally produced bearings was limited mainly to non critical areas of use.

An arrangement that guarantees availability of quality and sufficient quantities of raw materials is use of tolling treatment. Tolling minimises the need for huge cash flows and managing security for material movements. The experience of local end users showed their willingness to use local resources against the performance expectations. Foundry operators met and discussed with during the course of research fully understand the available avenues open to them for advancement of their businesses as individuals and through associations such as chambers of commerce and industry in their respective localities. Such initiatives have been accomplished through agreements made and submission of proposals to various government agencies and that is sufficient evidence of *empowered actions*.

Foundry operators have not merely sat back waiting for external players to initiate improvements in the business environment. However, it remains a reality that until some substantial financial and operational integrations are achieved by tolling arrangements with major users of bronze bearings, foundry operators will continue to

achieve below expectations and contribute little to the growth of the economy. It is also true to say that government in Zambia has fallen short on its policy implementations to grow businesses. There is much scope for improvements in all areas. One such area is training and exposure of foundry personnel in improvement of understanding and skills. Others are a stable macro-economic environment with affordable capital, suitable infrastructure and friendly taxes. A summary of visit reports and a suggested training programme are the **Appendices 8.1, 8.2, 8.3 and 8.5**.

4.3 MAGMASOFT simulation

As referred to in **Section 3.3**, a commercial package licenced by Advanced Metallurgical Technology (Ametex (Pty) South Africa) was used to simulate both the standard permanent mould production and the bearing sleeve resulting therefrom. The use of simulation technology in casting helps to substantially cut down costs of prototypes or trial castings. For the purpose of this work, production of moulds for commercial use (whether by conventional or 3D printing methods) would be made easier by adopting and making use of simulation results than would be the case otherwise.

The simulation results also indicated that conventional cooling of the casting was sufficient under the circumstances without the application of additional measures to achieve an acceptable microstructure in the products. Testing of different cooling regimes on the permanent moulds that were used to do trial castings and shown in Figs. *3.3c*, *3.3d* and *3.3g* of **section 3.3** would have been difficult to achieve under the circumstances.

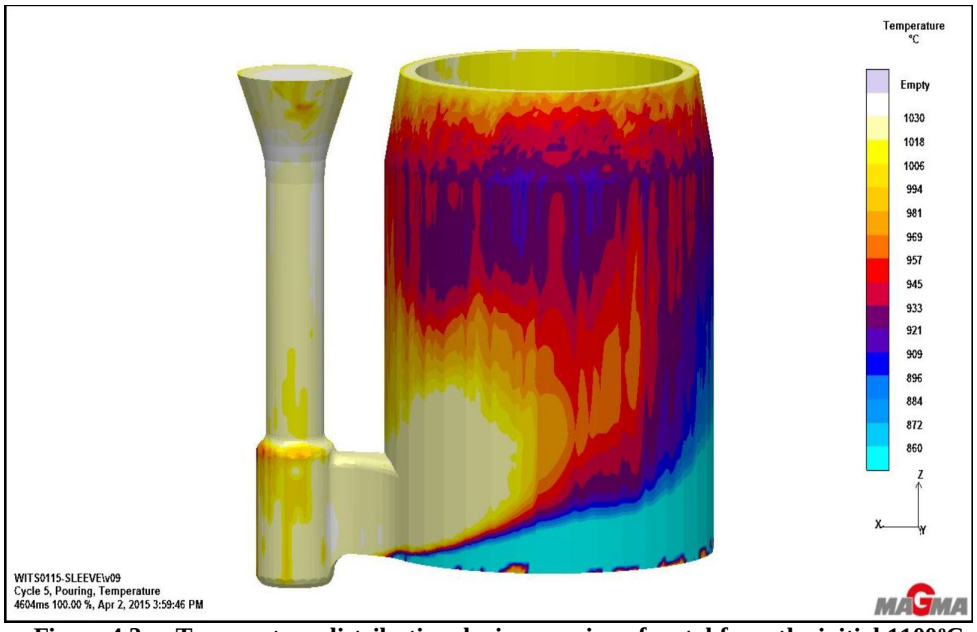


Figure 4.3a: Temperature distribution during pouring of metal from the initial 1100ºC
(Simulation by Ametex, April 2015)

The illustration in Fig. 4.3*a* is a simulation of an actual sleeve of standard or typical dimensions as indicated in **Appendix 7**. Filters and similar devices may be incorporated in the gating system to ensure laminar flow of the molten metal. The temperature indicator on the right shows that the hottest metal is in the down sprue and at entry into mould at the bottom. Solidification therefore progresses from the lower part of the casting towards its upper. The modulus during metal pouring as illustrated in Fig.4.3*b* showed a favourable feeding pattern. Although feeding from the bottom via the sprue is entirely by gravity without the need for pressure, complete mould filling is expected.

As a result a sound casting would be expected. In Fig.4.3*c*, simulation of likely hot spot areas was made which showed zones at which metal would remain liquid for an extended period of time. Hot spots lead to porosity or unsound castings. Castings HFC and HFD were produced at Heroes Foundry in Lusaka using the cast iron permanent mould produced by Zalco Limited of Kabwe (see Figs. from 4.3*d* to 4.3*g*). The mould

used in the simulation had similar dimensions with the cast iron mould from Zalco. The cast iron mould had however incorporated a taper along the length of the sleeve on the male portion. Feeding of the two castings done at Heroes was by gravity top pouring from a single point.

The yields in both cases were recorded at 66% and 86% respectively. Although surface appearances for both HFC and HFD were good, lack of complete fusion shown by red arrows in the casting bodies at several points rendered both unsound. The above simulations were not extended to the cast iron permanent mould in which the bronze sleeve was to be cast other than adopting its dimensions in the CAD presntation. It would be good practice however that the simulation technique is also used prior to mould production to ensure microstructural integrity of the product.

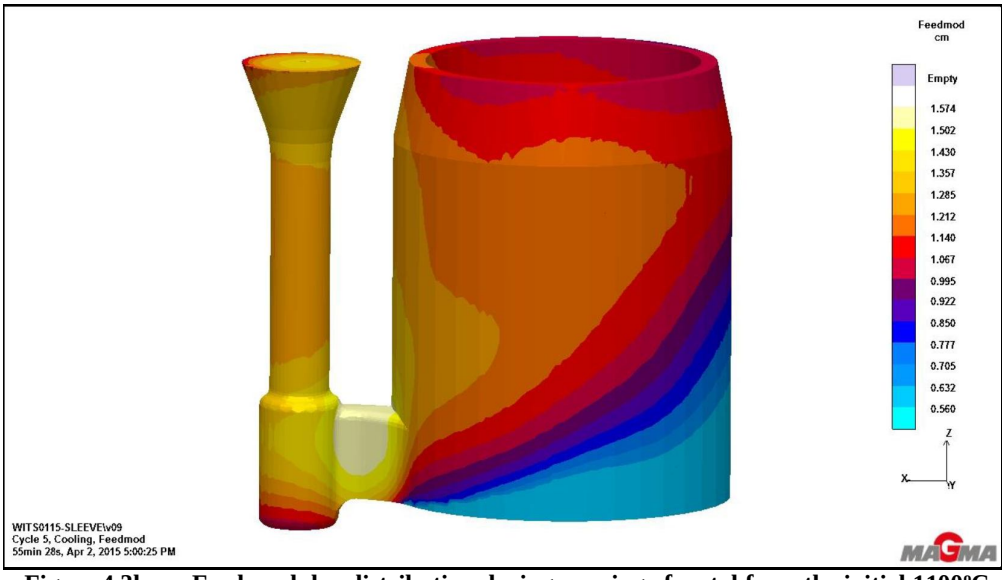


Figure 4.3b: Feed modulus distribution during pouring of metal from the initial 1100ºC
(Simulation by Ametex, April 2015)



Figure 4.3c: Likely hot spot locations in terms of portions of extended solidification times (Simulation by Ametex, April 2015)

Temperature distribution, modulus of feeding and likelihood of hotspot presence when used properly prior to and during casting of critical components such as bearing sleeves are important indicators of the probability of successful casting. The tools can be used to improve casting yield and eliminate rejection or scrapping of products.

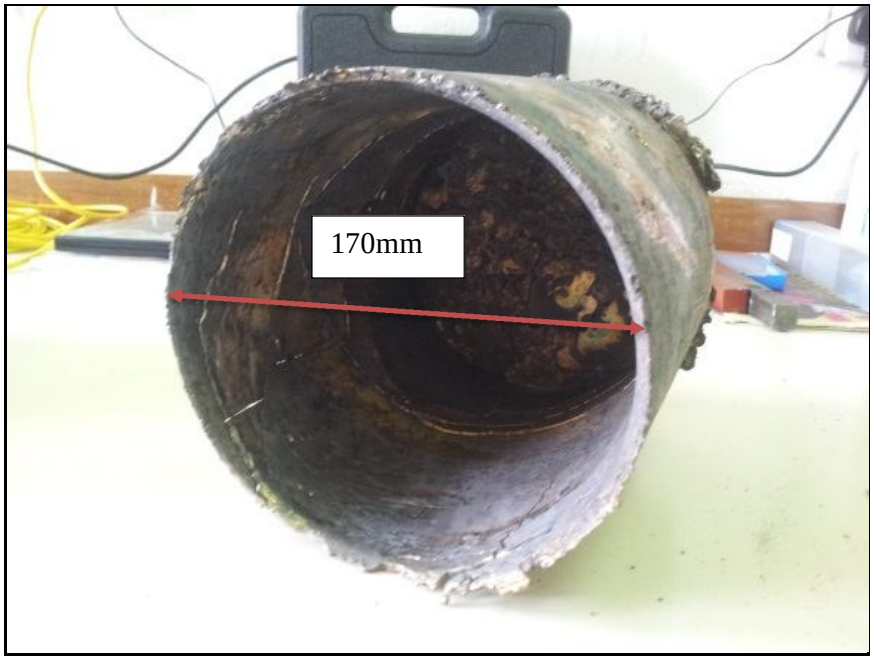


Figure4.3d: Casting HFC (Heroes, Jan. 2015)

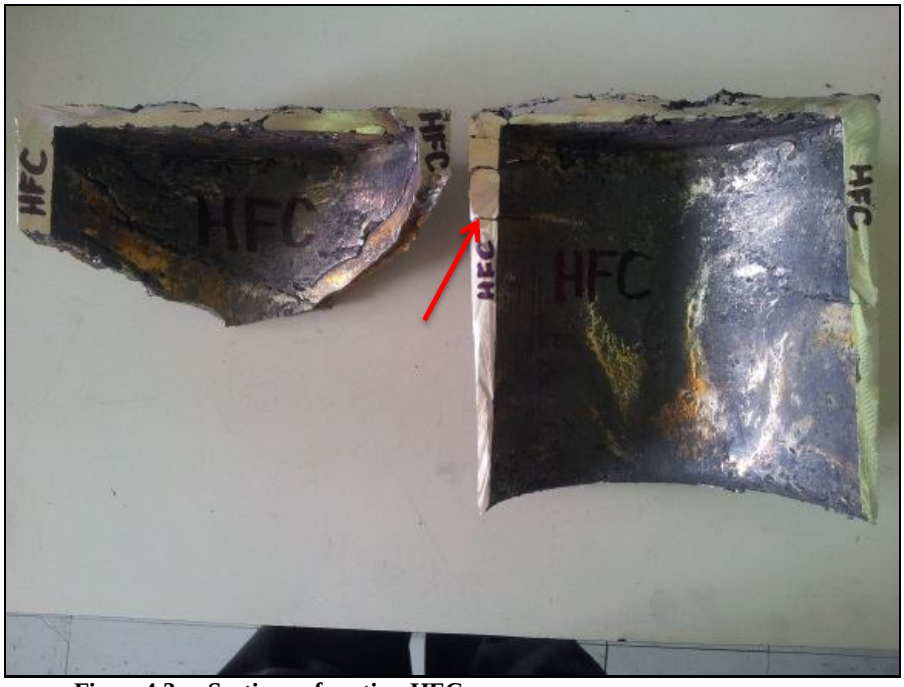


Figure4.3e: Sections of casting HFC

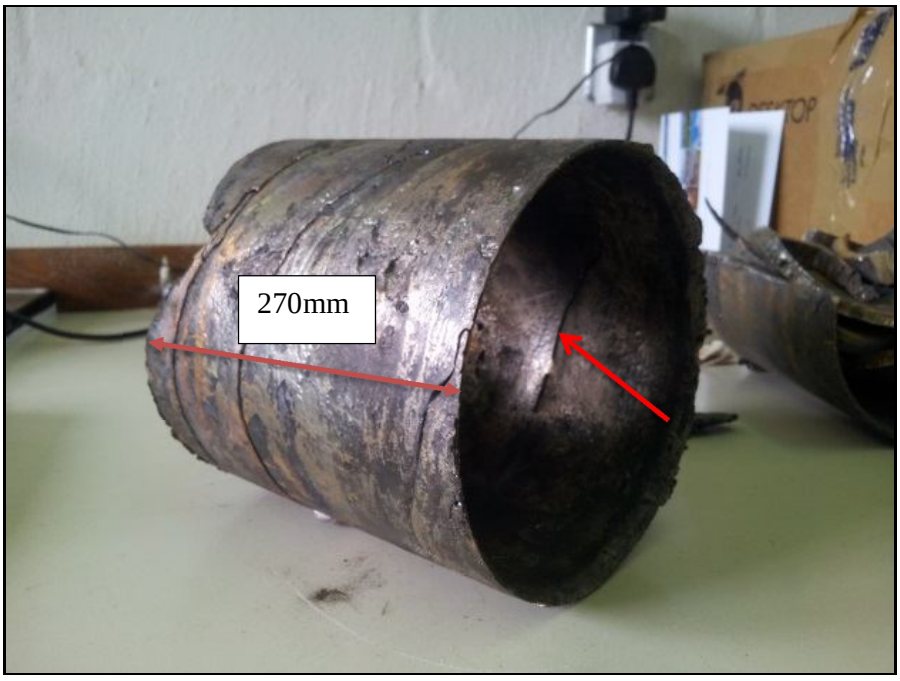


Figure4.3f: Casting HFD (Heroes, Feb. 2015)



Figure4.3g: Sections of casting HFD



Figure4.3h: Castings from the steel mould (UJ, May, 2015)

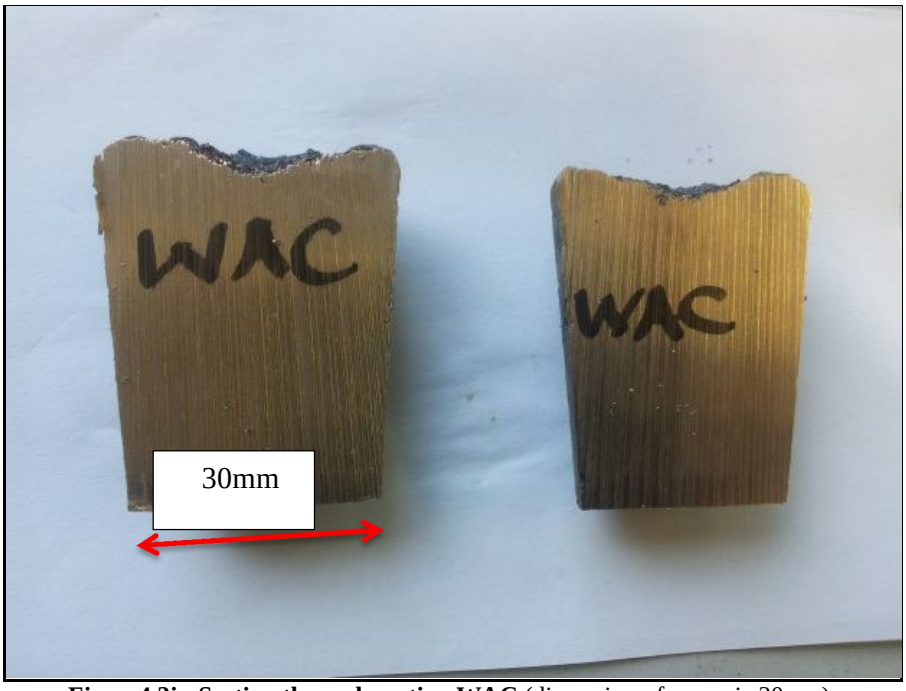


Figure4.3i: Section through casting WAC (dimension of arrow is 30mm)



Figure4.3j: Steel mould castings (UJ, May 2015)



Figure4.3k: Sections of castings prepared for metallographic and wear testing

By contrast, laboratory castings at the University of Johannesburg during May and July 2015 were less problematic. These were achieved using the steel mould shown in Fig.3.3*j* in which feeding was by gravity top pouring. The target charge weight for each casting was around 300 to 400 grams. Yields on the other hand varied greatly as duration of pouring or transfer of metal from furnace to mould was difficult to keep consistent or in control. In general all the forty (40) castings attempted appeared to be of sound quality with minimal or no pores and showed smooth external surfaces. This deduction was based on microstructures displayed in Figs.4.1.5k to 4.1.5r.

4.4 Energy utilisation at Fox Foundry

Data obtained from Fox Foundry on the facility's usage of used diesel oil for firing crucible furnaces was compiled and examined. Table 4.4a below shows the quantities of both diesel oil and cast bronze over a two year period form 2014 to 2015. A sample calculation of the energy required to melt a quantity of bronze at Fox Foundry was performed and is shown in **Appendix 11**.

Fox Foundry used 1,947 kWh of electricity energy equivalent per tonne of melted bronze in comparison to the expected value of 362 kWh per tonne of melted bronze. The figure of 1,947 kWh per tonne can actually be a lot higher than this if only the quantities of finished castings ready for despatch were used in calculations rather than those of just cast bronze from the furnaces. Despatch or sales figures of finished bronze were not readily available from Fox Foundry at the time of compiling the said data. It must be mentioned that it is more useful and appropriate to use quantities of finished castings rather than melted castings as the former incorporate a financial aspect that may be used to determine process costs.

Table 4.4a: Bronze production and fuel used at Fox Foundry in 2014 and 2015

	2014		2015	
	Bronze cast (kg)	**Fuel used (litres)**	**Bronze cast (kg)**	**Fuel used (litres)**
January	3,192	630	3,123	630
February	1,859	420	3,339	630
March	2,970	630	985	420
April	1,651	315	4,919	315
May	1,756	315	1,034	315
June	3,608	732	3,078	630
July	3,240	630	3,845	840
August	1,546	315	1,713	315
September	812	210	2,540	525
October	1,355	315	3,505	732
November	5,324	1,050	2,954	630
December	1,054	210	2,683	525
Totals	**28,367**	**5,772**	**33,718**	**6,507**

Using figures in Table 4.4a, Fox Foundry used an average of 199 litres of used diesel oil to melt a tonne of bronze. The foundry was paying around US$0.40 per litre of used diesel oil giving a total of US$80 per tonne of cast bronze. The US Dollar figures used are based on the exchange rate with the local currency at the time of writing which was

ZMW11 to USD1. The final sales figures in local currency were not readily available in order to determine the overall economics of operations. In addition a table of electricity tariffs for various categories of consumers in Zambia is given in **Appendix 12**. Using the rates shown and applying the maximum possible for commercial consumers, Fox Foundry would be expected to spend US$107 per tonne of cast metal inclusive of Government taxes as cost of energy.

The figure is based entirely on the total energy equivalent of the total quantity of used diesel oil. As stated earlier, Fox Foundry was unable to confirm their sales figures for the period under consideration. The cost of the finished casting however has a number of elements that include labour, post casting operations, marketing and general overheads that can add significantly to the overall cost. Despite the fact that Fox Foundry was aware of the potential for energy savings by waste heat re-use and thereby reducing production costs, no measures were put in place for doing so.

Summary

Foundry materials alongside those that were cast in a laboratory were examined in terms of composition of the four elements of copper, tin, lead and nickel. Foundry material compositions varied significantly within identified individual usage categories as well as across the different categories. Alloying elements were very low and non existent in most cases. Lack of implementation of dedicated quality measures throughout the production chains was the major reason for that. The ideal reference composition used was bronze alloy C93200.

The primary phase in the microstructures for the foundry materials was alpha solid solution with some duplex phases of alpha-beta as well dispersed lead globules. Porosity was evident and this impacted on hardness and friction properties both of which were higher than expected in the reference alloy. Microstructures in laboratory cast materials were finer and free of porosity. Although the measured hardness and coefficient of friction values were higher than expected standard at 130HV (85HV) and 0.25 (0.12), it was shown that it was possible to control composition and hence positively influence resulting mechanical properties.

CHAPTER FIVE

5. Discussion

Introduction

Work in the thesis examined possible ways of producing near net castings using permanent moulds (or die-casting) without the need for post casting machining. The perspectives presented in the following sections address the results or evidence obtained from the various tests conducted on collected samples or *foundry materials* as well as those cast at a foundry and in the laboratory or *castings*. Although more than eighty (80) samples were collected from various entities and up to forty (40) cast at a foundry and laboratory, tests possible on the said samples were limited. The tests were chemical analysis, hardness determinations, microstructural analysis and dry friction. The tests adopted were meant to offer a high probability of accomplishment at a small scale under-resourced foundry level.

However, consideration for inclusion of other relevant mechanical tests such as tensile and impact strength be given in future work once issues of sample size and shape are overcome for the benefit of better analysis than was possible on samples constrained by size. Technical aspects related to bearing performance that is *fit for purpose* are highlighted in sections 5.1.1 to 5.1.6. Additional skills in composition and temperature control, defect identification, sand preparation and testing are suggested for the shop floor worker other than the traditional skills of pattern making, moulding, melting and casting through training modules with a duration of a day at a time. Business sustainability and production costing is another area for attention in terms of skills development. The contents to be considered for inclusion in training modules for such skills development are included in Appendix 5.

5.1 Foundry materials and laboratory castings

5.1.1 The importance of composition in castings and impact of individual elements on properties

Alloying elements such as tin, lead and nickel as in the target alloy, C93200 as indicated in Table 4.1.1a, are added to copper for specific purposes of strengthening, corrosion resistance and machinability. The tested foundry materials (or OEMs) showed little or no presence of key alloying elements except only in residual amounts as they were all mostly below the C93200 specification. The mean compositions in weight percent for foundry materials were copper (86.2), tin (4.6), lead (1.8) and nickel (0.2). target compositions for the same elements were copper (87), tin (11), lead (1) and nickel (1). Getting the right composition for a casting offers a greater probability for attaining required properties referred to above. In the case of laboratory cast materials the amounts of alloying elements in weight percent were copper (80), tin (9), lead (4.5) and nickel (1). These were based on plots shown in Figs. 4.1.2a to 4.1.2d.

The additions of required amounts of tin, lead and nickel to the experimental castings did not confirm or dismiss significant differences in mean compositions between the experimental castings and the foundry material samples using the criterion of error bars. A comparison of copper content within groups of foundry materials showed that there was no significant difference statistically between the individual means due to overlap in the error bars. Raw materials in the production foundries in question are never really categorized for specific re-use and castings are prepared with any material that is available at the time. There were no trial castings at Fox Foundry using the experimental mould but that was possible at Heroes Foundry in Lusaka. It was not clear why copper

and tin at increased contents showed decline in friction values in both standard and test cast materials.

From the results presented in section 4, the presence in bearing materials of these elements; copper, tin, lead and nickel showed some correlations with hardness and friction properties of the bearings. The resulting R values in all plots was however below the 0.9 threshold. No repeat experimental castings were done for the same conditions and as such there was a limitation on assessing the behaviour of individual elements on key properties. High cost of input materials and availability of laboratory equipment at the University of Johannesburg were limiting factors. Figures 4.1.4*a* to 4.1.4*p* showed that relationships existed between element content and key properties, a fact that can be used or exploited to produce acceptable quality bearing castings. The increase in hardness for foundry materials (figures 4.1.4*e*, 4.1.4*n*, 4.1.4*i* and 4.1.4*k*) appeared to show the expected trend that an increase in alloying addition should result in higher hardness.

However the same increase in hardness with increased element content is true for copper also in Fig. 4.1.4*a* and that seemed to contradict the principle of solution hardening. The observed or apparent increase in hardness for foundry material samples is attributed in this case to lack of proper control of casting conditions at the foundries. These could have been influenced by factors such as metal cooling rate and sizes of individual castings rather than the presence of alloying elements. The behaviour of key elements with respect hardness was as expected in the case of experimental or laboratory castings as shown in figures 4.1.4*b*, 4.1.4*f*, 4.1.4*j* and 4.1.4*n*. For the laboratory castings operating conditions were closely controlled. The results clearly

showed that there was a relationship between cast microstructure and properties that could be applied and used successfully to obtain desired results at a small foundry level.

5.1.2 Hardness and friction properties observed in foundry material and castings

The comparison of mean hardnesses for foundry materials and test castings showed no significant differences when error bars were applied in Figs. 4.1.3a as given in the results section. That was also the case of no significant differences when mean friction properties were contrasted between foundry materials and test castings in Fig.4.1.3b. The foregoing error bar comparisons were based on two classifications only i.e. as (i) foundry material samples on one hand and (ii) experimental castings on the other. The t-test was applied to individual groups of samples within the two categories and with the exception of one case all showed that the hardness and friction properties were statistically significantly different from the expected mean values as shown by standard C93200.

Test castings were done in permanent moulds and under those conditions a finer microstructure was expected to lead to increased hardness and strength in the castings. The results suggested or demonstrated that it was possible in a small foundry set up to influence in a significant way properties of cast bearings to meet set standards. This can be accomplished through adherence to composition, processing and operating requirements. The tested properties of hardness and friction for all group samples for castings as well as foundry materials; LHTC, LMTC, LLTC, SHS, StdMStoc and SMS showed that the mean values for each group were statistically significantly different and higher than the expected standard values of 85HV and 0.12 with the exception of one result. Mean hardness t-test value for the SMS group of samples at 76.6 HV was

not statistically significantly different and lower than the expected standard mean. The threshold value of R for a meaningful correlation is 0.9 and that was not seen in nearly all plots from Figs.4.1.4a to 4.1.4p suggesting the apparent relationships may be attributed to conditions during casting. Other than for a single case, the plots revealed that the apparent changes in the percent contents of the elements analysed had little or no impact on the properties of the materials tested.

As noted in section 4, results of dry friction test results for collected or foundry samples and the experimental castings did not show any statistically significant differences between them. Both categories however were statistically significantly different from that of the standard C93200 using the t-test. Materials such as copper when used in their pure form for bearing applications tend to possess lower coefficients of friction than the alloyed forms. However pure materials will not have the necessary second phase constituents to support high loads under varying operating conditions of speed and temperature. Sadykov *et al* (1999) supported the above view when he studied key structural parameters such as phase composition and controlled grain size possible with addition of alloying elements in copper based bearings.

5.1.3 Impact of microstructure on bearing properties

The importance of a good and appropriate microstructure on cast properties is well known. There were some differences observed in the micrographs shown in figures 4.1.5*a* to 4.1.5*j* for foundry materials and 4.1.5*k* to 4.1.5*r* for experimental castings. In the former case, large grains and widespread porosity impacted negatively on mechanical properties. Rapid cooling in the case of experimental castings as a result of using permanent or chill moulds resulted in dense and pore free structures compared to

the foundry material samples which were sand cast. Upadhyaya *et al* (1997) suggested that a dense microstructure had beneficial effects on wear and other mechanical properties. The differences in wear behaviour between foundry materials and laboratory castings from test results were however not apparent.

Although there is no clear correlation between a bearing's mechanical properties and friction according to Yuanyuan *et al* (1996), elimination of porosity in a microstructure as was seen in the experimental castings is good for wear resistance. An alpha (α) phase structure or primary solid solution alone as seen in most of the collected foundry material samples was not sufficient to guarantee good bearing properties. Presence of harder beta (β) or the more stable delta (δ) and gamma (γ) second phases would result in better load bearing capacities than is possible in simple primary α structures. Vital second phase structures were only possible with the required minimum levels of alloying elements such as tin, lead and nickel which were missing in foundry material samples. Prasad (2004) and Equey *et al* (2011) also supported the view that presence of key second phase constituents in the microstructure of bearing materials was more beneficial than merely a good microstructure. While the copper element showed a wider variation in composition across the tested samples, there were no recorded significant differences in the properties of the bearing bronze measured.

5.2 Small foundries in the business of bearing production and role of Government

From the outset the research tried to also capture challenges faced by foundries or SURFs that lacked control on production processes and quality. In other words, by introducing specific control skills into the equation, a fit for purpose, cost effective, bearing is achievable. Use of a permanent mould such as one tested at Heroes foundry

is possible. Production in permanent moulds may be limited to a few product types but with the advantage of a high output. Having collaborated with one, Fox Foundry based on the Copper belt of Zambia, the focus of inquiry altered a little to also address issues of quality control on the factory floor as well as energy management. Fox Foundry was willing to collaborate and in many respects qualified as a SURF.

Fox Foundry would be regarded as a mid-tier foundry and like many others it relied entirely on recycled materials or scrap as feed material and often sourced from mining industry end users. The foundry may be capable of producing quality products at commercially competent prices. At the time of research the foundry was not equipped to test both input and output materials. Fox with some major improvements can turn into a competent foundry by turning to better insulated furnaces and applying energy efficiency principles such as preheating charge materials using waste heat from the process. At the time of this work, Fox Foundry was using approximately 200 litres of used engine oil (a mixture of various brands) to melt 1,000kg of bronze. The foundry was producing about 1,000 kg a week giving a yearly output of not more than 36 tonnes of bronze.

The foundry was using almost 7, 200 litres of waste oil for heating in a year and the estimates were based on figures the foundry provided. An analysis of the oil used is given in **Appendix 10**. Only one sample of oil was tested and indications showed that it also contained some moisture. According to the American Petroleum Institute (API) literature on calorific values of common fuels, the gross calorific value (GCV) of the used oil at Fox Foundry would be about 46,000 kJ/kg and was assumed consistent for waste oils used. There was no laboratory in the area with the ability to determine

calorific values for the oils. No special protection of furnaces is used to minimise heat losses or utilise the waste heat for other purposes. Materials are charged to the furnaces cold without any preheating. Secondary or scrap materials contain a lot of tramp elements and Fox would be better off classifying the input scrap according to application and that would yield better results. Heroes Foundry on the other hand suggested they used 400 litres of used oil to produce one tonne of bearing bronze. The challenges mainly lie in the following areas;

(i) Material acquisition and its security against theft,

(ii) Material assessment and selection agasint desired compostion limits,

(iii) Permanent Mould design and acquisition for common bearing sizes,

(iv) Process control,

(v) Energy conservation through use of efficient furnaces and heat recycling and

(vi) Skills upgrade for foundry workers.

With a moderate investment in equipment and skills, foundries in the position of Fox Foundry can actually turn around fortunes and compete favourably for a larger and sustained access to good markets. In the long term business sustainability can only be assured with a favourable arrangement of supply of metal or scrap input on a tolling basis with major users. Tolling agreements with such users should be viewed as fulfilment of financial and operational integration with the right sector players and a result of empowered actions. Another guarantee of sustainability is careful management of energy use of all types. The role of government in Zambia in promoting businesses in the manufacturing sector is projected in the manufacturing sector survey report of 2012 that has had direct impact on policy implementation since. All players in the

economy, local and external generally agree that maintenance of a stable macro-economic environment is key to supporting business. Effective interest rates in the economy however remain too high to support significant growth and stable financial development as well as compete favourably in local and international trade.

In recent times since 2012, there has been establishment of export and lower tax zones for businesses in a few towns and interest from would be developers is growing. The impact from such an initiative will only be felt in the years to come. Provision of economic infrastructure alone coupled with some general incentives on taxes may not be sufficient to make the intended businesses thrive. Infrastructure and incentives work well when government also makes it possible for similar types of businesses to re-inforce each other and augment their specialities as well as making markets easily accessible whether locally or international.

5.3 The power of simulation during design and production of castings

The two moulds used in experimental castings (Figures 3.3*e*, 3.3*f* and 3.3*g* as well as **Appendix 7**) were conceived and designed on the basis of typical products from a commercial set-up. They were not subjected to simulation tests prior to being cast and machined. However, the simulation assessment was applied on the larger mould shown in Figure 3.3*e*. A minimum number of one hundred (100) castings were assumed in this case and the total cost per casting would need to be worked out. Ductile cast iron was considered the preferred material. For similar compositions, ductile cast irons retain higher impact strengths than ordinary grey cast irons and well suited for handling purposes in a typical foundry.

Typically permanent moulds, gravity fed, will yield 10 000 or so castings. The objective of the simulation was to produce in electronic form a sound casting resembling the final casting as best as possible. The idea is to avoid costly downtime through scrapping of castings that do not meet given specifications. The simulation is a tool that would be used by the supplier of a permanent mould to a SURF and not necessarily the foundry itself. Simulations are done to yield useful information for the following purposes among others;

(i) Temperature distribution in the casting,

(ii) Modulus of casting during mould filling in a given time and

(iii) Prediction of porosity and hotspots

The above three criteria were favourable with respect to the casting design used as shown in Figures 4.3*a*, 4.3*b* and 4.3*c*. Temperature distribution and modulus were such that directional solidification was encouraged during mould filling. Highest molten metal temperatures coincided with source of metal giving an opportunity for uninterrupted feeding. High feed modulus ratios above unity (1) on the other hand were in areas in a position to provide feed metal to the casting in lower regions. The likely volume proportion of hotspots that would lead to porosity given extended solidification times was around 10%. If solidification time is reduced, the volume proportion also substantially decreases giving a good chance for a sound casting.

As mentioned in section 4.0, mould production and casting simulation were used to optimise the design parameters adopted for a typical commercial bearing product as shown in Appendix 7. An optimised design using CAD and simulation tools improves

delivery and avoids costly re-works and ensures appropriate cooling of cast product and resulting microstructures. For a small scale under-resourced foundry, an investment of around USD15,000 for tooling and production of a commercial mould, could support manufacture of several hundred bearing sleeves and recoup the investment. This was based on information given by Advanced Metallurgical Technology (AMETEX Pty Ltd. of South Africa) in 2015. This is a one off cost but attracts annual licencing fees specific to package entered into and estimated at around 10% of capital costs.

5.4 The potential for energy savings in the foundry sector

The energy deficit in Zambia today is real. This is brought about by both a rapid rise in demand across all sectors and a weak investment in hydro-power and other forms of electricity generation. As at year 2012, the installed and functioning capacity for power generation throughout Zambia was just under 2,000 MW among these three major companies; Zambia Electricity Supply Corporation (Zesco), Copper belt Energy Corporation (CEC) and Lunsenfwa Hydropower Company (LHPC). Another 1,700 MW was targeted to be added to the national grid most of which is hydro sourced and under Zesco while the rest would be fossil fuel generated using coal. Maamba Collieries Limited, a coal mine in southern Zambia, invested in thermal power generation.

Even with new sources of energy fully operational after 2018, power availability for many needs will continue to be constrained. The foundry sector has one relatively easier option to influence than others available. This is the control of processing and casting technologies over the other more difficult options of apital equipment, markets and metal prices. Small scale foundries and the sector in general should continue to pursue

ways and means of employing the use of better furnaces and power supply control mechanisms on them.

Where capital equipment such as induction furnaces can be upgraded, a retrofit solution would involve changing the mode of controlling power supply to the furnace by moving from ordinary thyristor control to insulated gate bipolar transistor (IGBT) control. The available power demand frequency may too be altered from mains frequency (MF) to any of the following; high (HF), very high (VHF) and medium (MF) and should be done to reflect furnace configuration to be used in a particular situation. All researchers on energy efficiency in foundries cited in section 2.2.8 above (Aluminium Feederation of South Africa, Rische *et al*., Environmental Sustainability Solutions, German Institute for Foundry Technology, Inductotherm and Customised Energy Solutions) agreed that over 75% of energy used in a foundry goes to melting metal.

Metal melting and subsequent holding in a furnace prior to casting is the area where the greatest opportunities. Other than metal processing technology and control mechanisms, the material or furnace charge being treated can be a focus for energy efficiency applications. In that regard a tool known as Materials Flow Cost Accounting (MFCA) is built into a model that recognises quantities of materials in use and their respective monetary values throughout the value chain. MFCA offers a more realistic picture of the cost of wastage in a production environment than do traditional approaches of management accounting. The Foundry Materials Loss Model (FMLM), a variant of the MFCA, if applied diligently to a specific situation can reveal among other things major drivers of losses in a foundry and possibilities for adjustment of loss rates to improve recoveries and efficiencies.

Furnace equipment manufacturer, Inductotherm Corporation of United States, emphasises a good understanding of the foundry energy bill with reference to among others; utilities' base charges, power factor penalties as well as on and off peak rates. Inductotherm also stresses that available power demand must be managed and controlled in a manner that fits the melting configuration requirements of a foundry. Inductotherm also notes that heat loss from a molten metal surface by radiation rises exponentially with temperature representing a huge proportion of total heat lost in addition to that by conduction through furnace walls and its auxiliary structures.

Customised Energy Solutions of India's model of assessing energy usage in a foundry offers interactive monitoring of a production situation at remote point locations from the foundry. Each foundry load or energy centre can be represented in a hierarchical structure seen in Fig.2.2.8f. Every branch of the tree or energy centre is monitored continuously giving real time output data via LAN links and web based communication systems. The model allows definition of several process and operational parameters the basis of which are used in discussions with plant personnel. The data obtained coupled with discussions may then be used to effect changes to practices in the processes or operations that benefit energy efficiencies.

Summary

Small foundry operators rely heavily on bronze bearing scrap from end user industrial plants including the mines in the case of Zambia. As the scrap was not analysed by the foundries prior to its use as raw material, final composition of material input to furnaces was mainly left to chance. It is rare that virgin or pure metals on their own only are used for production of new bearings at the foundries visited. Sometimes pure copper may be added to bronze melts as a way of satisfying production tonnages only. Compositional

control is not practiced. Although the type of operations may be described as that of a jobbing foundry, output from these operations is mainly a handful of similar types of products made repeatedly and in a sense resembling that of a production foundry.

From the chemical analysis results of foundry material samples, only copper was close to that required in the standard composition. Measured hardness and friction values for both foundry material and laboratory castings samples were both higher in comparison to the standard UNS C93200. The impacts of individual metallic elements on the measured properties could not be clearly distinguished in the *foundry materials* or those that were produced by foundries and supplied to mining companies. An estimate for the final product costs was difficult owing to the haphazard nature of costs of input scrap and unreliable energy usage figures given (except in the case of Fox Foundry where some working figures were arrived at which showed that the facility was utilisation nearly twice the required theoretical value to melt a tonne of bronze). The use of energy there could not be considered cost effective and sustainable for that matter.

CHAPTER SIX

6. Conclusions

Introduction

The thesis work tested thicker castings using a permanent mould than foundries were mostly doing. Thicker castings is a market where SURFs will need to make an impact on in the immediate future. As a way of concluding, the drive towards improvement should examine the use of permanent moulds or dies, employment of mandrels for thicker wall castings and where possible use continuous casting methods. Based on results of testing foundry bearing samples, test or trial castings at a foundry in Lusaka as well as the University of Johannesburg's Metal Casting and Technology Station (MCTS), conclusions noted in the sections below were arrived at.

Further, simulations of castings in a permanent mould were undertaken with the assistance of the MCTS using MAGMASOFT and the results from there supported part of the conclusions. Use of MAGMASOFT and other proprietary software for an under resourced foundry should be considered as an external input or resource rather than as an in house tool. This is due to prohibitive costs involved in acquisition and licencing of such software. Reliable short run production of commercial quality bearings is not sustainably achievable in a typical SURF foundry in Zambia at a cost that represents value for money. The reasons or aspects contributing to that finding are elaborated upon under the individual headings on raw materials used and their impact on final properties, management of production processes, energy utilisation, use of special tools in casting design and financing and training opportunities available.

The research hypothesis that quality bronze alloy bearings can be sustainably produced in under-resourced small scale casting facilities in Zambia was a reasonable assumption to make. The hypothesis was reasonable under prevailing circumstances because of the following three major factors; (i) major raw material copper was and remains available in Zambia, (ii) there is also availability of a ready market in mining and related industries and (iii) there was sustained support by favourable government policies that were aimed at encouraging value addition enterprises such as the foundry sector.

6.1 Foundry materials, standard or OEM bearings

6.1.1 Quality of foundry materials in terms of composition

All foundry materials tested including those those from end users showed no significant differences in chemical composition between the various categories identified. That was the case for all elements of copper, tin, lead and nickel as indicated in Tables 4.1.1a and 4.1.1b and Figs. 4.1.2a to 4.1.2c in the results section of this report. The characteristic desirable bearing composition to be used or applied in such castings should reflect that given in the reference alloy, C93200.

6.1.2 Impact of foundry materials on microstructure, hardness and friction

The mean hardness value of foundry materials across all categories identified was HV104.8. The mean coefficient of friction on the other hand was 0.38. Both values of hardness and coefficient of friction were higher than the expected standard as given in the results section in Table 4.1.1a. There were large variations in the two properties by both locally produced foundry materials and those imported into the country as OEMs

as shown by the deviations. The essential load bearing second phase constituents in the microstructures were missing in the samples examined as indicated in micrographs 4.1.5a to 4.1.5h. The hard copper-tin delta phase provides the essential wear resistance while the softer alpha phase plays the role of withstanding shock loading in the bearing component.

6.2 Test castings at foundry and laboratory

6.2.1 Quality of test castings in terms of composition

Compositions used in the test castings for all elements of copper, tin, lead and nickel were similar to the target standard material UNS C93200 as shown in Table 4.1.1b. The box plots or error bar charts in Figs.4.1.2a to 4.1.2d showed that mean values for element compositions were statistically significantly different. It was possible therefore at the level of small foundries to produce bearing materials with the right chemical composition.

6.2.2 Impact of test castings on microstructure, hardness and friction

Microstructures seen in test castings as depicted in Figs.4.1.5i to 4.1.5p in the results section showed fineness of grains and absence of porosity. The presence of harder second phase constituents were evident. Test castings also showed that it was possible to obtain the right mechanical and wear properties for a target application. However, hardness and friction properties measured on the test castings like in the foundry materials were found to be higher than those of standard alloy UNS C93200.

6.3 MAGMASOFT simulations

Simulation demonstrations using MAGMASOFT in Figs.4.3a to 4.3c of the actual size of the bronze alloy bearing revealed information on real time temperature distribution, molten metal modulus and occurrence of hotspots. The results of the simulation showed that it was possible to obtain a sound casting with favourable cooling rates for a typical bearing bronze casting as tested. Use of the MAGMASOFT simulation package enabled review of the sleeve casting process without the need for undertaking the actual casting.

6.4 Ways to save energy in a foundry

6.4.1 Used diesel oil for melting at Fox Foundry

Fox Foundry on average utilised 2,000 kWh or $7.2x10^9$ Joules of energy to melt one (1) tonne of bronze as determined from production figures during the period 2014 and 2015 as indicated in Table 4.4a in the results section. The figures relate to raw castings and not finished production. The energy required to melt 1 tonne of bronze is 362 kWh which is estimated to be twice the theoretical energy value of 181 kWh per tonne (or $6.51x10^5$ Joules). See also **Appendix 11**. Therefore, the energy consumed by the foundry was more than five (5) times than the theoretical requirement.

6.4.2 Monitoring of material flow, foundry energy bill and real time data

The Foundry Materials Loss Model (FMLM), a variant of the Materials Flow Cost Accounting (MFCA), offers a direct way of looking at material usage in the foundry as a way of saving energy. This is an alternative to focussing entirely on processes, operations and quality of equipment in use. An understanding of the entire perspective of the foundry energy bill was the first step in attaining sustainable energy savings in

an operation. It is possible to measure and record real time data in a foundry operation and provide for access at many remote points world wide via web based technologies.

Summary

The characteristics of foundry or OEM materials examined for two foundries and some end users showed a very wide compostion range and a lack of key alloying elements of tin, lead and nickel. This was attributed to lack of quality control measures applied throughout the production value chain. Tested properties of microstructure, hardness, friction and wear showed significant departure from those of the standard target alloy of C93200. Although compositional and microstructural control were attained to a large extent in the trial castings, no statistically significant differences in the said properties of hardness, friction and wear were established between the foundry materials and castings. Both categories of materials showed departure from the standard C93200.

Simulation software and other similar tools proved useful for the design and production of test castings and eliminates the need for costly trials. The ever rising cost of energy should serve as a good incentive for lowering the cost production and making output from small under-resourced foundries more competitive. Lastly training and diffusion of skills to foundry personnel was important in maintaining understanding of processes and operations. All the above aspects referred to thrive well in a good social environment with practical governemt support.

CHAPTER SEVEN

7. Recommendations

Introduction

The recommendations suggested in sections 7.1 to 7.5 are based on results highlighted in section 4 and are related to the foundry material samples and those that were cast in the laboratory and at Heroes Foundry. Further recommendations are given on suitability of small foundries for bearing production as well as use of simulation for bearing design and production. In addition, national sector policies targeted at foundry production should be aligned in such a manner that significant support is accorded to skills and technology development for artisans and tradesmen. Training institutions in conjunction with technology centres work together to support innovation, a key ingredient for sustainability.

7.1 On standard or OEM bearings

7.1.1 Sorting and grading of input materials

All purchased and acquired materials should be sorted and graded according to usage. Four major application areas with regards to the Zambian Copper belt mining industry; (i) hydraulics, (ii) mining hoists, (iii) ore crushing and (iv) general usage. Incoming materials to foundries should be accompanied by quality assurance certificates where that is possible. SURFs and other foundries can implement wet analysis methods to check compositions of materials on site as suggested in section 7.1.2. Small scale foundries should seek to establish toll treatment arrangements with major users of bronze components such as the mining industry. Such an arrangement would guarantee

the supply of input scrap metal and also a ready market for finished goods. This is in addition to securing supplies for hardener alloy metals and other critical raw materials.

7.1.2 Chemical analysis by wet methods

Graded materials must be sampled and analysed using basic techniques of chemical analysis and suitable to the foundry shop floor. That should be applied to materials being processed on a batch or continuous basis and final products on the other hand. Such a step would guarantee process quality assurance.

7.1.3 Further work on laboratory cast material

More castings should be produced using the cast iron permanent mould with the view of testing the following two factors; feeding method other than direct gravity pour and cooling rate. Suitable equipment for the purpose such as use of a tilting furnace would be required in that case.

7.2 Suitability of small foundries for bearing production

7.2.1 Feeding of metal and heavy castings

Small scale foundries should consider alternative ways of molten metal feeding of castings other than the commonly used gravity pour. That would allow for better control of cooling and achievement of cleaner castings. Small scale foundries should gradually expand product lines from just “Fit for Purpose” items to include components in heavier castings that are in great demand in surface mining operations in Zambia. This step can only be achieved with implementation of appropriate quality control measures throughout the production chains.

7.2.2 Capital goods market and training programmes

Small scale foundries should do everything possible to take advantage of the capital goods market in the Zambian mining sector that is supplied almost entirely by foreign firms. Small scale foundries should consider implementing regular training programmes (as suggested in Appendix 5) for shop floor workers at trade and artisan levels without neglecting the diffusion of engineering and other higher skills. Technology diffusion rather than technology transfer guarantees know how and understanding of everything well.

7.3 Casting simulation

Investment in commercial casting simulation packages such as MAGMASOFT by Ametex (Pty) Limited of South Africa should be considered by Fox Foundry and other small foundries. This allows simulation of production of moulds and castings and eliminates costly trials. Capital investment in such tools is however considerable and pooling together of resources by a group of foundries could be considered instead. A single foundry in addition to its work can produce permanent moulds for others and minimise the burden of capital investments required.

7.4 On ways to save energy in a foundry

7.4.1 Implement energy saving measures and audits

Fox Foundry and other foundries in a similar situation should consider implementing energy saving measures and undertake energy audits regularly. Such audits help to check that energy usage is within acceptable limits. That would be in addition to upgrading of capital equipment when the situation allowed it and improvement of

process management. Figures from the production data of Fox Foundry showed that the foundry was using more than five times the amount of energy than they otherwise would to accomplish their tasks. The situation on energy usage at Heroes Foundry was not any better than that Fox Foundry and cannot be said to be cost effective or sustainable for that matter.

7.4.2 Foundry material flow, energy bill and real time data

Fox Foundry and other foundries in a similar situation should look at material flow characteristics in the production process as a complimentary tool for energy saving. A full understanding of the energy landscape affecting operations as well as implementing an inexpensive inhouse system of monitoring vital production data would be useful.

Summary

Small scale foundries should pull resources together and invest in the procurement of permanent moulds and related technologies as opposed to one foundry bearing all the costs alone. Permanent moulds can be available in a few strategic sizes to minimise post casting machining. To deal with production costs exhaustively, small foundry producers should consider adopting the use of tools or software that show in full all process activities and related cost drivers. In this way the full cost of production is a lot clearer than otherwise. Government support in the form of appropriate policies to small scale businesses such as those in the foundry sector should aim at encouraging resource based industrialisation and manufacturing. That should go hand in hand with good trade policies, strong fiscal and macro-economic environments.

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Appendices

1. Visit to bronze foundries on the Copper belt and Lusaka

1.1 Purpose of visit and contribution to research objectives

Following email and telephone contacts with individuals on the Copper belt and Lusaka, visits were made to seven (7) facilities as indicated in a table at the end of the report. The visits were undertaken between Tuesday 11th and Saturday 22nd June 2013. The objective was to discuss the production of bronze used for bearing application purposes and see the plant in use in each case. For end users of bronze bearings, information was sought with regard to bronze quality and quantity requirements and difficulties encountered in the usage of the bronze on equipment. In addition, for end users especially, information was sought on models applied to their businesses and challenges faced in the environment.

The outcome of visits was to contribute to the research objective of characterisation of required bearing output from candidate foundries. Prior to the 1990s, there were two large players in the non-ferrous sector including the then mining conglomerate Zambia Consolidated Copper Mines (ZCCM). Another was Scaw Metals Ltd., a supplier of ferrous materials such as mill balls and liners. Both ZCCM and Scaw Metals discontinued the non-ferrous business and disposed of their plant following privatisation of the mining sector in Zambia.

1.2 Production and usage practices found

Of the seven facilities visited, five were manufacturers and two end users. Non Ferrous Metal Works of Ndola was the oldest and most experienced in the business having been established at a time mines were developing on the Copper belt. On the other hand, Fox Foundry was the newest and at present doing the most to gain market share. All producers visited were using sand moulding and casting with molten metal batches of no more 500kg at a time using oil fired furnaces seen in the photo in Fig.A11. All producers visited were private, family or individually owned businesses. Zalco with its manufacturing facility at Kabwe discontinued production of bronze ingots and opted to do a variety of copper based semis for export instead. Zalco suggested that the change-over was mainly due to their inability to deal with porosity problems associated with the production of bronze. The real reasons though may have had something to do with finances. It was probably thought that it was more financially beneficial to export semi processed metal than invest in production of finished bronze components.



Figure A11: Preparation for casting at Fox Foundry, Kitwe (June 2013)

End users at both Konkola Copper Mines (KCM) and Mopani Copper Mines (MCM) talked to did not appear to have a direct control over the quality of the bronze material they used for general machining purposes. The bronze was in most cases ordered through the company's purchasing department. However, the Concentrator department at KCM had a unique arrangement with a supplier of OEM parts and that arrangement seemed to minimise problems related to material quality. In the case of haulage trucks used at surface mining such as the vehicle in Fig.A12, replacement bronze parts were tied to contracts with suppliers of the equipment. There was never the less for local bronze producers to tap into this niche market.. Major uses of bearing bronze were identified for the following equipment;

(i) Crusher drive shafts
(ii) Underground ore loading skips
(iii) Overhead gantry cranes
(iv) Milling machine spur gears
(v) Hydraulic components for open pit haulage trucks

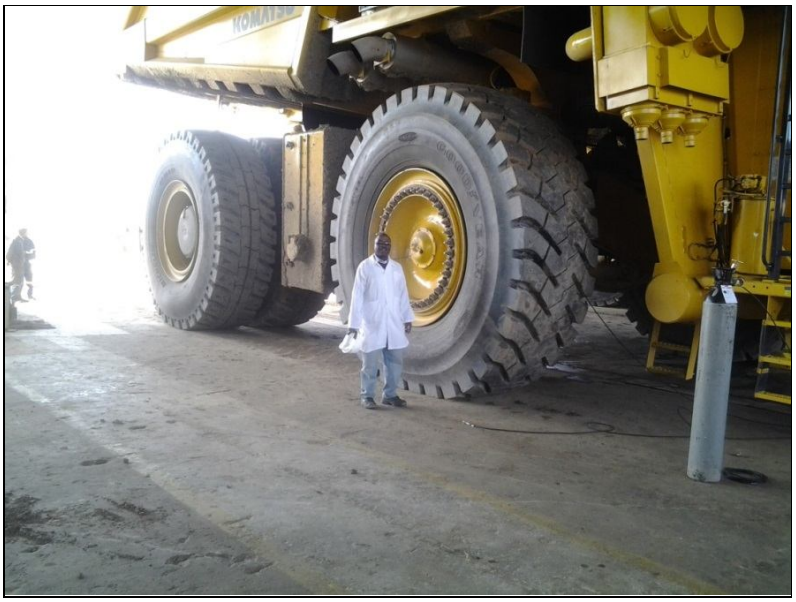


Figure A12: Open pit haulage trucks of payload 200 tonnes use massive bronze cylinders in their hydraulic systems (June 2013)

1.3 Follow up actions and recommendations

Random samples analysed

A total of seven random samples were collected from Heroes Foundry and Engineering (HEF), MCM and Non Ferrous Metal Works (NFM). A chemical analysis of the major elements was undertaken for all samples in addition to mechanical and metallurgical testing of samples from HEF (see sample analysis in Appendix 8). Levels of key elements of tin and lead appeared to vary a great deal and were below recommended thresholds for the type of bronze required. It was also likely that there was a significant presence of contaminants in the MCM samples not reported in the analysis. The observation made on the MCM samples also applied to those from NFM although in the case of the latter, the analysis indicated that the samples were more of pure copper than anything else. It was established during the visit that NFM was a major supplier of bronze materials to MCM and a lack of agreement in the results of random samples was an indication of the presence of quality problems both at the supplier and user.

Lead and tin contents of the HEF samples did not reflect conformance to any of the known bronze standards in common use for bearing applications. Tin content in the two samples was below the expected value of 10% while lead varied significantly. Hardness measurements on the HEF samples did not agree with the chemical analysis reported. Sample HEF1 with higher tin content than HEF2 would be expected to have higher hardness under similar cooling conditions but the results showed otherwise. Different section sizes and cooling conditions of HEF1 and HEF2 samples collected may have been responsible for the hardness results observed.

Recommendations

The visits undertaken to some producers and users of bronze bearing materials highlighted some challenges faced by the Zambian industry. In the case of producers, sustaining quality of bronze output seemed to be difficult and that translated into low competitiveness for end users in their respective businesses. Arising from the above preliminary observations, the following two are recommended;

(i) Plan collection and analysis of more samples from the three entities stated above and include Fox Foundry, KCM, Metso Minerals and Zalco Limited. Collect samples also from some South African producers and user companies for comparison purposes.

(ii) Discuss with producer and user companies for collaboration on a quality monitoring programme and appropriate training for shop floor employees.

LUNGU Chozi V

July 2013

No.	Company and addresses	Type of business	Production facilities or end use	Contact persons
1.	Zalco Limited PO BOX 30973 LUSAKA Tel. +260-21-122-1331 Metalco Industries Limited Plot no. 9119 Mulungushi Road Chowa KABWE	Currently produces copper and copper based alloys in semi-finished form. Items are for export only and none is turned into usable form as earlier attempt (more than 4 years has passed) to do bronze bearings failed due to consistent poor quality such as blowholes.	Located in Kabwe, 140 km north of Lusaka. Combined furnace technology and products cast as ingots from different types of copper and its alloys as well as scrap.	Chad HAKAMANGWE chad@metalco.co.zm chad776498@iconnect.zm Terana: +260-97-660-8527 +260-96-630-0410 Teddy ZULU +260-95-050-3914 +260-97-710-9084 Kapai: +260-97-781-6631
2.	Heroes Foundry and Engineering Plot no. 183/1 Muzilikazi Road Heavy Industrial Area PO BOX 37427 LUSAKA	Manufacturers of cast iron, bronze, brass and aluminium products. Important supplier to many machinists around Lusaka such as Bearing World. Can cast 600 mm max. diameter and up to 2 m length with weights of 300 kg max.	Oil fired and electric furnaces being installed (June 2013).	Herold BANDA Herod_banda@yahoo.com +260-96-643-2316 +260-97-787-0353 +260-95-599-9749 Dickson NGWENYAMA +260-97-875-0766
3.	Mopani Copper Mines Engineering Services Department Nkana Mine KITWE	Operates underground, concentrator, roaster and refinery. Company has Mufulira mine located 45 km north east of Kitwe. Two facilities have a combined output of more than 100,000 tonnes of refined copper annually.	Orders bronze billets from mainly Fox Foundry and Non Ferrous Metal Works. Preferred sizes are 100 mm and 200 mm dia. and length of 600 mm. Each mine uses several hundred kg to a tonne per month (see quality specification attached).	Justine BWALYA justine.bwalya@mopani.com.zm +260-21-224-7238 +260-97-752-3830 Raphael KATEKETA

No.	Company and addresses	Type of business	Production facilities or end use	Contact persons
4.	Fox Foundry Blantyre Road KITWE	Non-ferrous foundry and has been in business close to three years. Originally a motor vehicle spares trader (Fox Motors) and following commercial difficulties saw an opportunity in metal processing.	Oil fired crucible furnaces of 300 kg and 500 kg capacities (refer to photos in section 2 above). Casting is done in vertical moulds and metal flow is intermittent. Machine shop significantly adds value to its bronze ingots.	Chiti CHINGAMBO Email: fox.foundry@microlink.zm +260-97-790-8888 +260-96-690-8888 +260-95-522-2011
5.	Konkola Copper Mines Plc	Operates underground, concentrator and smelter. Company has Chilila-bombwe and Nchanga mines about 20 km apart. The Konkola Deep is a new project at Chililabombwe. The two mines have a combined output of more than 300,000 tonnes of finished copper annually.	Stores orders from NFM, Fox Foundry and United Engineering for use at machine shops. The mine's concentrator has a contract with Metso Minerals for the supply of bearings and other components for OEM equipment.	Lackstone MUSONDA Learner Development Centre lackstone.musonda@kcm.co.zm +260-97-757-3624 John MWANZA john.mwanza@kcm.co.zm +260-21-235-0941 +260-97-731-2198
6.	Metso Minerals (Zambia) Limited Plot no. 1043 Blantyre Road PO BOX 20269 KITWE	Supplier of bronze materials to industry and Nchanga Mine is a major client. The type and quality of bronze materials were not given for reasons of supplier-client confidentiality.	Metso Minerals has its principal manufacturing company based in South Africa for the region.	Jessy LUNGU jessy.lungu@metso.co.zm +260-21-223-1177 +260-97-740-2726

No.	Company and addresses	Type of business	Production facilities or end use	Contact persons
7.	Non Ferrous Metal Works (Z) Ltd. Plot no. 5155, Zambia Road Heavy Industrial Estate PO BOX 72283 Skyways NDOLA	Manufacturer and supplier of bronze and other non-ferrous metals to industry. Has operated since period of development of mines on the Copperbelt in the 1940s.	Facility has three furnaces (2 induction and 1 oil fired of capacities 300 kg and 600 kg resp.). Sand casting with maximum weight of casting at 200 kg. Cathode copper and scrap used as raw materials and degassed with phosphor bronze. Produces up to 15 tonnes per month when orders are good.	Levy DAKA levydaka@yahoo.com sales@nonferrousmetalszambia.com +260-21-265-1603/4/5 +260-96-856-1419 +260-97-726-5238

2. Visit to foundries in Johannesburg

2.2 VISIT TO WUMA HANDCRAFTS, 143 7th AVENUE, EDENVALE (Monday 11th March 2013)

1. Introduction

WUMA Handcrafts produces general household fixtures and décor in aluminium casting using a gas fired crucible furnace. A collection of hundreds of moulds with new designs are used to service the artificial sand casting process.

Certified ingots of aluminium alloyed with small amounts of strontium are supplied by a vendor and are re-melted for various uses.



Sikeli MOYO operating the gas fired crucible furnace



Pouring aluminium metal into various moulds

The outfit employs four persons one of whom is part time. Operating owner, Mr. Hennie BEKKER, undertakes overall responsibilities including marketing of the products.

A hired artist creates moulds for new items on order. Artificial sand moulds baked on parent metal (Al alloy) moulds are used for pouring molten aluminium and the metal is de-gassed before final casting.

2. The process

Certified ingots of aluminium form the bulk of raw materials used at WUMA handcrafts in addition to in house re-cycled scrap. The output from the factory is largely dictated by customer requirements that are secured through expositions and participation in trade exhibitions and fairs.

Re-melting of the ingot aluminium with subsequent degassing (probably using Nitral tablets) is done before casting into moulds. Mould preparation, melting and casting are done in one section of the foundry and managed by one person.

The rough castings are cleaned by knocking and grinding off excess metal. Initial fettling is followed by rough polishing of the castings in a vibrating vessel packed with lubricated cobble like media. Final polishing of the castings especially the smaller sized ones is done on rotating wheels with the aid of polishing compounds. Final machining is done on some parts for the purpose of assembly or attachment to other parts.

The photo on the right shows various types of pots (sauce and baking pans) as well as other casserols after the final polish. The final finish is excellent with virtually no blemishes on the surface and the items able to retain lustre after long exposure to various environments.

The aluminium pots weigh a fraction of their cast iron equivalents and possess excellent heat conductivity properties.



3. The market and future prospects

WUMA Handcrafts has distribution networks within the Republic of South Africa as well as Namibia and Zambia. Trade fairs and other targeted sales events help to market the unique hand finished castings of WUMA. Ideas in interior decors are endless as prospective customers continue to demand more and more unique products.

Mr. Bekker suggested that immediate improvements to the WUMA process was sought in the area of metal melting. The gas fired crucible furnace currently in use presented difficulties in energy conservation and temperature control.

There were a lot of heat and metal losses during transfer of molten metal to the moulds as that was done in small batches. WUMA therefore seeks to install a more efficient furnace unit utilising new technology. The operator expressed satisfaction with the rest of the post casting operations.



Decorative towel rails and flash mounted hand basins are among many of the household interior products cast at WUMA Handcrafts. Many of the designs have now been standardised and used for many years at WUMA. Increasingly though customers make their own input for new unique designs to suit a variety of occasions.

One off products have a high initial cost because of artistic and mould designs requirements.

4. Recommendations

(i) WUMA should consider independent testing of purchased aluminium ingots once every quarter or for every tonne of metal purchased. All items produced may be linked to a batch for quality assurance purposes

(ii) Once new melting equipment is installed, consider adding a holding furnace where metal to be cast will be drawn from

(iii) Casting ladle is better handled or operated from an overhead crane

Lungu C V

2.3 VISIT TO WAM METALS (PTY) LTD., ANDERBOLT, BOKSBURG, JOHANNESBURG (Thursday, 29th August 2013 at 10.00 hrs)

1. Introduction and brief of process

Professor Anthony Paterson and I made a visit to WAM metals on the date above. The visit started with a discussion on the objectives of my PhD research on casting of bronze bearings. The host manager, Gavin, explained that his company did not handle any bronze materials but brass and aluminium alloys only. It had been more than ten years when he last dealt with bronze castings but he however had some working experiences to share. At the time of the visit, WAM Metals was in the process of reorganising its production and expanding certain facilities. The company essentially had two units; (i) casting of brass and aluminium alloys and the subsequent secondary forming into bars or plate like shapes and (ii) forging and machining of final products.

A tour of both facilities referred to above was made. Aluminium cast stocks were at the time produced by a batch process using permanent moulds while brass was by continuous casting using a modified Bruggmann and Junker GmbH machine and technology. The brass continuous casting facility is a twin system and production rates are reasonably high. New casters are also being installed for aluminium. An onsite spectrographic laboratory was in place to check composition of metal from both melting units and final casts.



Casting of aluminium ingot bars in permanent moulds at WAM
(29th Aug. 2013)

2. Lessons from the WAM Metals process

Gavin explained that nickel as an alloying element in minor quantities in bronzes was a crucial addition. Other than microstructural refinement, nickel assisted the casting process of the bronze by ensuring fluidity. The process of batch casting of aluminium ingots using permanent moulds as seen in the picture above can be applied to production of bronze sleeves as proposed in my PhD research. Use of permanent moulds can ensure near net shapes and eliminate the bulk of machining costs post production.

Lungu C V

3. Visit to Lusaka and the Copper belt by research supervisor

Report Visit to Zambia

Research project: Sustainable production of quality bronze alloy bearings in under-resourced small scale casting facilities (in Zambia)

A) **Introduction.**

The project follows the Zambian Government (MCTI) strategic objective No 3 (Strategic Plan 2011 to 2015) of value addition through mobilising MSME's (Micro, small and medium industries to create wealth and employment though investment of resources, business linkages and industrial cluster incubators. Whilst small business is an important employment creator, due to the rate of failures it is also an employment destroyer. One of the major causes of failure is cash flow. A report on the website Econ3X3 is written by Andrew Kerr, Martin Wittenberg and Jairo Arrow (from UCT). They used Stats SA data to estimate the contribution of big and small firms to job creation and job destruction. The major finding was that large firms contribute more to net job creation than small ones. One reason for this is found in the roles of unions in RSA. More importantly, globally, most failures within three years of start-up are cash flow related. It is very difficult for small firms to borrow money from banks - and even more difficult for micro businesses. Hence one is looking for both a market and a low capital technology response. A second core need is broad Government support.

The project is intended to address the dual concern of value addition to locally mined minerals and sustainable employment in a way that is as simple as possible and as complex as necessary. It overlaps casting technology, value addition to local resources, and socio economic issues. The intent is to develop appropriate technology and understanding that may be applied in the production of quality bronze sleeve bearings for hydraulic equipment operated by mines on the copper belt in small or medium level Zambian foundries with minimal facilities and which can apply lean technology (low capital cost) control methods (as a result of an inability to procure modern production and testing equipment). To move forward there is an interim need to move back to basics, which, once understood, form a platform for advance. Ongoing mentorship would assist progress.

To meet the purpose, opportunities and constraints, the intent is to investigate simplification of composition, testing, casting and machining technology both to a level than can be managed simply and where technology diffusion (transfer of understanding as distinct from simply method) is achievable. It is anticipated that competent founders could use the fundamental understands as a stepping stone to improved approaches. In effect the approach is to step back from modern technology approaches to an achievable, but well understood, starting point with a view to commercial and technology advances.

The production process needs to be robust. The metal is envisaged as sourced from spent bronze castings sweetened with virgin materials where necessary. Research seeks to offer a robust, timely and economical cast solution. Appropriate size cast and machined, bronze sleeve bearings of correct composition and mechanical properties cost effectively replacing those directly machined from standard virgin alloy bar stock varieties would reduce the cost of metal and of machining. An economical trade-off between bearing performance and total cost (including the lost production effects) is envisaged. Note that a similar project was envisaged by the NFTN ((RSA) National Foundry Technology Network) through Mintek. The particular challenges of access to finance and metal security against theft led to the development of the tolling approach.

Six main challenges are pertinent:

1. Bearing material composition. Sourced from used castings a range of qualities mainly practically characterised by wear and ductility is postulated. An economically effective method of achieving a robust range of compositions sufficiently meeting wear property dominant and, alternatively, impact dominated operating conditions is envisaged.

2. A casting method that will produce correct mechanical properties and grain structures for specific operational circumstances.

3. Technology diffusion as distinct from transfer. The need to successfully transfer understanding management and safe control of hot metal and of the casting methods and appropriate controls required to produce a competent completed bearing to candidate

founders. This is rather like the skills training of a coded welder, a specific skill set. The technology training would need to be accompanied by a sufficient business training to enable an understanding of managing costs and time and an ability to determine a selling price and quote. This requires the development and application of training material and a technology diffusion programme.

4. Selection of suitable candidates – may require pre testing. Consider source of payment to candidates, if required. It may be possible to run a pilot as a final year student project.

5. A tolling solution to materials, financial inputs and security issues. Cash flow viability of production, working capital related primarily to the cost of the base metal. Concerns related to bank support, metal acquisition and protection against theft are envisaged as requiring a tolling approach. In this case customers provide and retain ownership of the metal and provide security. They pay only for conversion to a finished product.

6. Sustainability. Whilst the core purpose is to produce bearings for mines, sustainability may require lean technology alternatives between orders Small business incentives made available by government agents would be expected to add to sustainability'.

B) Objectives

The purpose of the visits in Zambia were to:

1) Report back on progress to the University of Zambia, Lusaka.

2) Examine the experimental permanent casting mould as produced with a view to introducing suitable product cooling methods to ensure the grain structure required.

3) Acquire more sample material for hardness, wear and microstructure examination.

4) Investigate potential Government legislative and resource support for emergent rural foundries operating under the auspices of copper belt mines.

5) Investigate market support from intended customer mining companies for a tolling system based on casters operating inside their properties, non-transfer of ownership of metal, and paid a fee for conversion to a useful product.

6) Investigation of a lean technology (low capital and low equipment) market possibility in the tourist sector for cast products

Results

The scale of the market is a concern. The original tolling model assumed that there was sufficient market at a specific mine to be viable. This may not be the case. The market potential for cast bronze bearings of the size that can be successfully cast as a result of the research intervention programme needs to be determined. Over and above the domestic sales of wear parts to mines, domestic opportunities for brass and bronze cast products exist both in durables and in tourist mementos.

The research programme fits well into the policy framework of adding value to locally produced minerals to increase both the wealth of the county and to provide employment. However the approach has not been well communicated to affected Ministries. The main market opportunity appears to be in supporting foundries in the copper belt by adding value through appropriate metallurgy applied from a lean technology viewpoint.

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20/07/2014

4. Matrix layout using five factors and each varied at three levels

No.	Composition	Temperature	Pouring	Weight	Feed
1	7	1000	2	1	1
2	7	1000	2	1	2
3	7	1000	2	1	3
4	7	1050	3	2	1
5	7	1050	3	2	2
6	7	1050	3	2	3
7	7	1100	4	3	1
8	7	1100	4	3	2
9	7	1100	4	3	3
10	11	1000	2	1	1
11	11	1000	2	1	2
12	11	1000	2	1	3
13	11	1050	3	2	1
14	11	1050	3	2	2
15	11	1050	3	2	3
16	11	1100	4	3	1
17	11	1100	4	3	2
18	11	1100	4	3	3
19	14	1000	2	1	1
20	14	1000	2	1	2
21	14	1000	2	1	3
22	14	1050	3	2	1
23	14	1050	3	2	2
24	14	1050	3	2	3
25	14	1100	4	3	1
26	14	1100	4	3	2
27	14	1100	4	3	3

Composition: Tin content of bronze in percent at 7, 11 and 14%.

Temperature: Casting temperature varied at 1080, 1100 and 1150 ^{o}C.

Pouring: Duration of laminar pouring where ‘2’ represents a shorter time than normal, ‘3’ normal pouring time and ‘4’ a higher than normal pouring time in seconds.

Mass : Mass or volume of casting using ‘1’ lower than optimum size at 35 grams, ‘2’ optimum size at 40 grams and ‘3’ above optimum size of casting at 45 grams.

Feed: Feeding method by ‘1’ direct gravity pour, ‘2’ basin or side feed.

5. Proposed training modules for foundry personnel

1.0 Introduction

6.0 Acknowledgements

The author in conjunction with the University of Zambia would like to express sincere thanks to the following persons for their invaluable advice and assistance during the course of preparation of this short course in melting and casting of bronze for sleeve bearing applications.

Name	**Position**	**Institution**
Prof. Anthony E Paterson	Professor and Researcher	Wits University, Johannesburg, RSA.
Mr. Stan Muwowo	Curriculum Development Specialist	TEVETA, Lusaka Zambia.
Mr. H Banda	Manager and Owner	Heroes Foundry, Lusaka.
Mr. C Ching'ambo	Manager and Owner	Fox Foundry, Kitwe, Zambia.

It must be acknowledged that the frameworks that guide basic training for a lot of trade qualifications in Zambia exist under the authority of TEVETA. The three major areas or career profiles for a foundry trade worker of Pattern maker, Moulder/Core Maker and Melter are covered in appropriate subject matters approved by TEVETA. The training modules proposed here are meant to deliver additional knowledge and skills in area of melting and casting and the associated auxiliary functions rather than replace the core training in the trade.

1.2 Rationale

Although output from the Zambian manufacturing sector and in particular the metals sub-sector has not grown significantly over the years, the need for specialised knowledge and skills is huge. That is evidenced by the continued low value-added un-beneficiated export of the mineral and metal resources at the country's disposal. On the other hand importation of finished industrial components, spares and manufactured goods keeps rising.

The focus of this research is on bronze bearing used by the mining sector for open-cast mining. Any improvements in the manufactured quality of bronze sleeve bearings by local foundries has a significant impact on the competitiveness of the sector especially with regards to growing of market share and creation of beneficial employment. The modules proposed in this short course therefore seek to bridge the existing knowledge and skills gap.

1.3 Objective

To capacitate rural foundry industry personnel with appropriate up to date knowledge and skills in the preparation of charge materials from scrap metal sources, melting and casting of bronze sleeve bearings to acceptable national and international standards. The foregoing is to be accomplished with the highest standards of personal and plant safety.

1.4 Expected outcomes

On completion of the short course, the participant shall be able to;

(i) Apply and suggest methods of material and metal characterisation

(ii) Sample any material in the production stream for analysis purposes

(iii) Use simple criteria to mix different grades of alloys to form desired composition

(iv) Cast a bronze bearing completely, near net shape, without porosity or cracks and with appropriate microstructure

(v) Apply the necessary safety procedures before, during and after melting and casting of a given metal.

1.5 Duration

The proposed duration of each module is twenty four (24) contact hours inclusive of laboratories, demonstrations and visits and spread over a maximum of three days. Additional time may be agreed for the purpose of practical demonstrations or working visits to a casting facility.

1.6 Outline

Module	Title	Duration minimum (Days)
One	Basic metallurgy of bronzes and copper alloys in general	1
Two	Casting defects in bronzes and their remedies	1
Three	Mould making processes	1
Four	Melting of bronze in furnaces	1
Five	Pattern making and methoding of castings	1
Six	Sand quality and testing	1
Seven	Business and sustainability aspects in a small foundry	1
	Total duration	**7**

1.7 Delivery strategy

Learning shall constitute lectures, discussions, laboratories, practical demonstrations and where necessary plant visits to production sites.

1.8 Evaluation

The University of Zambia in conjunction with TEVETA shall evaluate the short course in terms of the standard procedures currently in use and as agreed. The evaluation shall include formative and summative components where as in each case the following shall be defined; *objective, areas of evaluation, evaluation instruments* and *sources of information*.

1.9 Entry requirements

The proposed entry requirement is simply presenting proof that the person is a practicing foundry man with or without formal trade qualifications. Evidence of Grade 9 school attendance or its equivalent with a pass in English should be considered the absolute minimum.

1.10 Attendance and assessment criteria

All registered candidates shall be expected to attend all sessions of the course and as course is not examinable no assessments other than confirmation of attendance shall apply.

1.11 Staffing

Must be a recognised or accredited trainer of a national institution with a teaching qualification and in possession of at least a diploma in metallurgy or a related field. In addition a minimum of two (2) years industrial experience shall be required.

1.12 Progression and certification

The module courses are not examinable and no progression requirements shall apply unless in the case of longer than the 1 day duration applicable to a single module and more than one module involved at a time. A certificate of attendance shall however be awarded by the University of Zambia.

1.13 Testing of applicability with UNZA undergraduates

The above course material formed part of what was tested on final year metallurgy students in their Foundry Technology course at the University of Zambia during the years 2016 and repeated in 2017. The bronze material used was selected from the scrap also used in the laboratory trials at the University of Johnnesburg. Casting method used was based on sand with adopted mould dimensions as shown in **Appendix 7**. All working parameters of melting and casting temperature, method of metal pouring and cooling rate were set to suit the process of learning by the undergraduates. Part of the

exercise required testing of material composition before, during and after casting as well as examination of casting material for porosity and quality of the microstructure. Hardness measurements were also undertaken on the cast samples. On the other hand field tests on the permanent mould were undertaken at Heroes Foundry in Lusaka as described in section 3.2 of this report.

2.0 Module One: Basic metallurgy of bronzes and copper alloys in general

Objective

To understand the nature of chemical compounds and how these are formed in metals

Learning outcomes

(i) Explain what a chemical compound is

(ii) Explain what a solid solution is

(iii) Show the benefits of mixing types of metals

(iv) Detail the alloys of copper and their properties

(v) Demonstrate how to measure basic properties alloys

Scope

Metallurgical knowledge helps in selecting materials as well as how they will be processed. According to the Foseco Non-Ferrous Foundryman's Handbook (Brown, 1999) there are essentially eight (8) major categories of copper based alloys. Theses are with major alloying elements indicated in brackets;

(i) *High conductivity coppers* (almost pure copper)

(ii) *Brasses* (Zinc). Corrosion resistant and good for plumbing and marine uses

(iii) *Tin bronzes* (Tin). Corrosion and wear resistant. Useful in boilers

(iv) *Phosphor bronzes* (Tin and phosphorus). Good for higher load and speed bearings as well as gears

(v) *Leaded bronzes* (Tin and lead). Good for low to moderate load and speed bearings

(vi) *Gunmetals* (Tin, zinc and lead). Corrosion resistant and pressure tight castings. Popular for valves and pumps as well as bearing use as substitute for leaded bronzes

(vii) *Aluminium bronzes* (Aluminium). High strength and corrosion resistant. Marine and architectural applications

(viii) *Copper-nickels* (Nickel). Marine applications in severe conditions

The module explains the different categories of copper based alloys such as brasses and bronzes and the impact of alloying elements on the final properties of the metal. Leaded bronze materials are by far the most widely used for casting of bearing components by small foundries in Zambia such as Fox Foundry. However, it is not uncommon to have materials from the other categories of copper based alloys mixed with leaded bronze especially phosphor bronzes.

Course content

1. Structure of bronzes, theory of alloys, equilibrium diagrams and solidification of bronze alloys
2. Composition and classification of bronzes, factors affecting hardness and strength of bronzes and alloying for different applications
3. Steps in bronze bearing casting design and choosing the correct alloy type for an application

3.0 Module Two: Casting defects in bronzes and their remedies

Objective

To understand the nature of casting defects and how they are formed during metal treatment

Learning outcomes

(vi) Explain what a casting defect is and how many types are possible

(vii) Show how casting defects are formed

(viii) Explain the various techniques used in identifying defects

(ix) Explain the importance of sound castings

Scope

Casting defects can assume various forms on the cast surface, sub-surface, as a shrinkage or dimensional problem to cite but a few. A proper understanding of the reasons why these defects arise is necessary for the correct diagnosis and remedy of the defects. Causes of defects are discussed as well as precautions that may be taken to minimise their occurrence.

Course content

1. What is a casting defect?
2. Types of casting defects; surface and internal, gases, mould and metal reactions, misruns, inclusions, structural defects, factors influencing defects

6. Causes of defects and remedies taken. Use of cause and effect as well as statistical process control (SPC) tools for improved quality control

6. Methods used in detecting defects such as non-destructive testing using ultrasonics, dye penetrants and x-rays and importance of sound castings

4.0 Module Three: Mould making processes

Objective

To understand the processes and operations involved in green sand mould making

Learning outcomes

(i) Explain how a mould is formed and the elements that constitute a mould

(ii) Explain the nature of different types of sands used in mould making

(iii) Appreciate the automated mould making systems

(iv) Explain bonding techniques for different types of moulds

(v) Describe the mechanical properties of moulds

Scope

Selection of the appropriate moulding technique is crucial for final properties of a casting. Various types of moulding techniques are discussed as well as those that based on computer aided design techniques and the 3D systems used in mould production.

Course content

1. What is casting mould?
2. Elements of a mould and automatic moulding
3. Mechanical properties of moulds and moulding sands

5.0 Module Four: Melting of bronze in furnaces

Objective

To understand the principles of metal melting and mixing of different types of metals

Learning outcomes

(i) Explain the conditions under which melting happens
(ii) Detail the energy requirements for melting a given alloy
(iii) Prepare charge make-ups for different requirements
(iv) Show the effects of alloying additions to the base metal
(v) Explain the difference in use of crucible and induction furnaces for copper alloys

Scope

Melting techniques used in copper alloys as well as selction of furnace type between crucible, induction or other. Furnace maintenance practice is explained as well as post melting processes and pouring techniques used.

Course content

1. Melt preparation. Importance of superheat and pouring temperatures

   Quality control during and after melting. Control and specifications for copper and

   bronze scrap, alloying elements and treatment chemicals. Rapid identification and classification of different scrap materials to avoid the harmful effects of tramp elements and to rationalize the use of expensive scrap. The concept of quality assurance requires that quality should be built into the castings during the manufacturing process. A good quality assurance system costs money to implement and maintain but the high costs are offset by reduced scrap rates and higher customer satisfaction.

4. Post cast treatments and safety considerations.

6.0 Module Five: Pattern making and methoding of castings

Objective

To understand the steps involved in design of castings and materials used in production of patterns.

Learning outcomes

(i) Explain what a pattern for a casting is and how it may be produced

(ii) Detail the steps involved in pattern production

(iii) Explain the different techniques available for pattern making and their relative costs

Scope

A pattern that is finally used for production of a casting mould evolves from an engineering drawing design. While basic techniques for doing so are still used widely these days, new and modern ones involving computer based proprietary software have gained prominence in recent years. Additionally production of patterns themselves is increasingly being automated by the growing field of 3D printing that eliminates costly wastage and greatly improves the quality of castings.

Course content

1. What is pattern making?
2. Materials used in pattern making
3. Pattern design steps
4. Allowances used in pattern making

7.0 Module Six: Sand quality and testing

Objective

To understand the role of a good quality sand in the moulding processes

Learning outcomes

(i) Explain what the nature of a moulding sand is

(ii) Detail the properties of a good quality moulding sand are

(iii) Explain the key properties of a moulding sand

Scope

The importance of a good quality moulding sand with a high fusion rate is cannot be over emphasised. Although water continues to be a commonly used moulding sand binder, various resin systems are also available particularly for use with artificial sands.

Course content

1. Nature and types of moulding sands
2. Additives used in moulding sands
3. Sand testing methods
4. Sand reclamation and environmental control

8.0 Module Seven: Business and sustainability aspects in a small scale foundry

Objective

To understand that business sustainability involves a number of aspects that include financial, environment and social responsibilities.

Learning outcomes

(i) Explain what a business is and some of the factors that directly influence it

(ii) Explain the meaning of financial, environmental and social sustainability

Scope

Small and medium sized businesses face a lot of challenges that threaten their survival. Whilst technological skills and materials may be readily available for production, finanacial literacy and a good know how for treatment of costs remain major hinderances to achievement. Small foundries in particular face the challenge of cash flow management and security of input materials as well as output products.

Course content

1. Business objectives and sustainability
2. Understanding the operational environment and market for a business
3. Material inventory
4. Cost drivers and costing models in production

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6. Identification of samples collected during course of research

No.	Sample ID	Description	Area of application	Source of sample
1	FFA	Billet section	Machining stock for sale	Fox Foundry, Kitwe
2	FFB	Gating metal	Recycling stock	As above
3	FFC	Impeller scrap, standard stock	Recycling stock	As above
4	FFD	Impeller scrap, standard stock	Recycling stock	As above
5	FFE	Thrust ring, standard stock	Recycling stock	As above
6	FFF	Thrust ring, standard stock	Recycling stock	As above
7	FFG	Used bearing, semi-circular	Recycling stock	As above
8	FFH	Counter shaft 590x240x120 mm	Machining stock for sale	As above
9	FFI	Used bearing, flanged sleeve	Recycling stock	As above
10	FFJ	Used bearing, flanged sleeve	Recycling stock	As above
11	FFK	Used bearing	Recycling stock	As above
12	FFL	Counter shaft 590x240x120 mm	Machining stock for sale	As above
13	FFM	Impeller scrap, standard stock	Recycling stock	As above
14	FFN	Counter shaft 590x240x120 mm	Machining stock for sale	As above
15	FFO	Counter shaft 590x240x120 mm	Machining stock for sale	As above
16	FFP	Solid billet 250x50 mm	Machining stock for sale	As above
17	FFQ	Bushing 95x70x110 mm	Recycling stock	As above
18	FFR	Bushing 165x110x290 mm	Recycling stock	As above
19	FFS	Solid billet 250x50 mm	Recycling stock	As above
20	FFT	Bushing 290x130x300 mm	Recycling stock	As above
21	FFU	Bushing 160x130x300 mm	Recycling stock	As above
22	FFV	Counter shaft 590x240x120 mm	Machining stock for sale	As above

No.	Sample ID	Description	Area of application	Source of sample
23	FFW	Solid billet 150x600 mm	Recycling stock	As above
24	FFX	Thrust ring 410x315x20 mm	Recycling stock	As above
25	FFY	Counter shaft 590x240x120 mm	Machining stock for sale	As above
26	FFZ	Solid billet 200x300 mm	Recycling stock	As above
27	FOA	Bushing 385x50x45 mm	Recycling stock	As above
28	FOB	Solid billet 200x75 mm	Recycling stock	As above
29	FOC	Bushing 150x140x350 mm	Recycling stock	As above
30	FOD	Bushing 160x130x290 mm	Recycling stock	As above
31	FOE	Counter shaft 590x240x120 mm	Machining stock for sale	As above
32	FOF	Bushing 155x140x500 mm	Recycling stock	As above
33	FOG	Bushing 400x135x30 mm	Recycling stock	As above
34	FOH	Bushing 95x70x110 mm	Recycling stock	As above
35	HFA	Billet section (HEF1)	Machining stock	Heroes Foundry, Lusaka
36	HFB	Billet section (HEF2)	Machining stock	Heroes Foundry, Lusaka
37	KCA	Secondary crusher liner	Stock for laboratory casting	Konkola Copper Mines, Chingola
38	MCA	Used bearing (MCM1)	Gland water pump sleeve	Mopani Copper Mines, Kitwe
39	MCB	Used bearing (MCM2)	Crusher shaft barrel bush	As above
40	MCC	Used bearing (MCM3)	Locomotive support bearing	As above
41	MCD	Used bearing	Pump rotating element	As above
42	MCE	Used bearing	Bending machine	As above
43	MCF	Used bearing	Pump shaft sleeve	As above
44	MCG	Used bearing	Crusher shaft barrel	As above
45	NFA	Billet section (NFM1)	Machining stock for sale	Non-Ferrous Metal Works, Ndola
46	NFB	Billet section (NFM2)	Machining stock for sale	Non-Ferrous Metal Works, Ndola
47	HFC	Test melt at Heroes Foundry	Bearing	Charge mixture

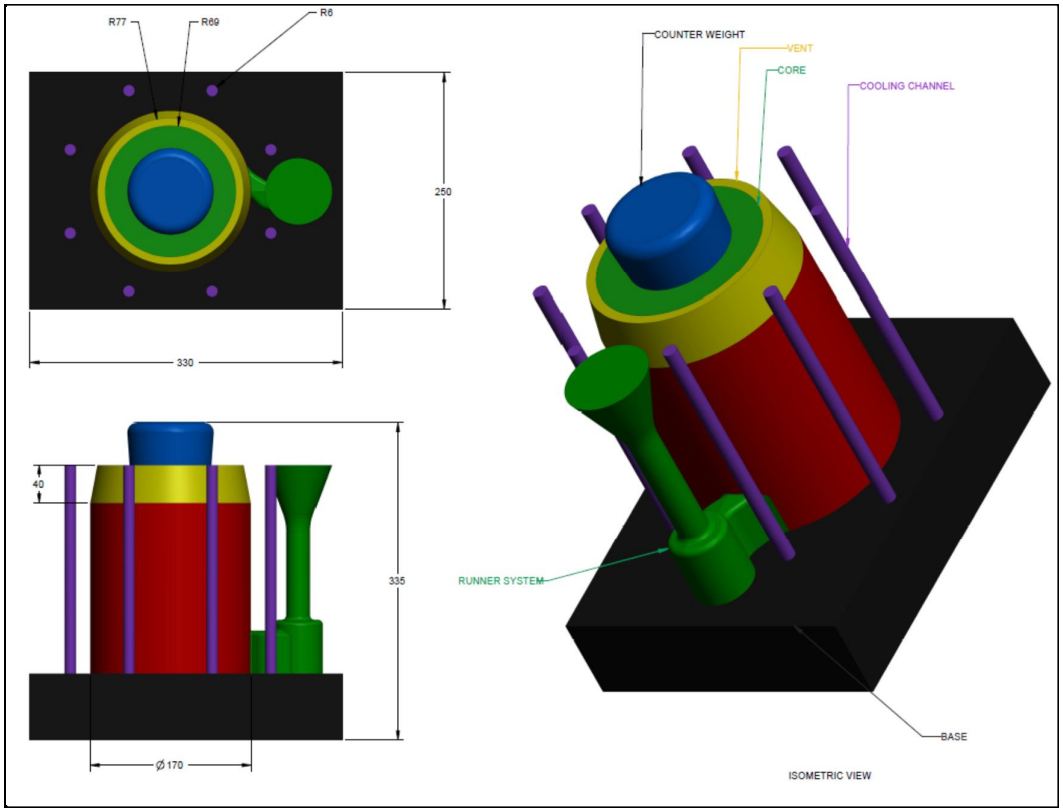
No.	Sample ID	Description	Area of application	Source of sample
48	HFD	Test melt at Heroes Foundry	Bearing	Charge mixture
49	FOI	Solid billet 90x110 mm	Machining stock for sale	Fox Foundry, Kitwe
50	FOJ	Sleepers 30x400 mm	Stock for sale	As above
51	FOK	Bushing 40x20 x100 mm	Stock for sale	As above
52	FOL	Rope guide 80x40x20 mm	Stock for sale	As above
53	FOM	Flat bar 260x30x700 mm	Stock for sale	As above
54	FON	Billet 100x80x450 mm	Recycling stock	Zambia Sugar
55	FOO	Ring 680x450x20 mm	Recycling stock	Zambia Sugar
56	FOP	Sleeper 300x500x50 mm	Recycling stock	Zamefa
57	FOQ	Bushing	Recycling stock	Fox Foundry, Kitwe
58	FOR	Impeller 770x100x260 mm	Recycling stock	As above
59	FOS	Impeller 80x50x150 mm	Recycling stock	As above
60	FOT	Impeller 100x80x200 mm	Recycling stock	As above
61	FOU	Flat bar 30x500 mm	Recycling stock	As above
62	AFC	Impeller scrap	Recycling stock	As above and FFC repeat
63	BFD	Impeller scrap	Recycling stock	As above and FFD repeat
64	CFE	Thrust ring	Recycling stock	As above and FFE repeat
65	DFF	Thrust ring	Recycling stock	As above and FFF repeat
66	WAA	KCA mixed to C92500	Cast at UJ	Cast at 1150 deg.
67	WAB	KCA mixed to C92500	Cast at UJ	Cast at 1150 deg.
68	WAC	Comp. remained as KCA	Cast at UJ	Cast at 1150 deg.
69	WAD	FOU mixed to C92500	Cast at UJ	Cast at 1150 deg. no Cu needed
70	WAE	FOR mixed to C92500	Cast at UJ	Cast at 1150 deg. no Cu needed
71	WAF	HFD mixed to C92500	Cast at UJ	Cast at 1150 deg. Cu was missing
72	WAG	HFC mixed to C92500	Cast at UJ	Cast at 1150 deg. Cu was missing

No.	Sample ID	Description	Area of application	Source of sample
73	WAH	FOI, FOM mixed to C92500	Cast at UJ	Cast at 1150 deg. Sample scrapped
74	WAI	FOT, FOL mixed to C92500	Cast at UJ	Cast at 1120 deg.
75	WAJ	FOO, FOP, FOQ and FON to C92500	Cast at UJ	Cast at 1120 deg. 29g Cu was missing
76	WAK	FOJ, FOS and FOK mixed to C92500	Cast at UJ	Cast at 1120 deg. 3g Cu was missing
77	WAL	FFA and FFB mixed to C92500	Cast at UJ	Cast at 1120 deg.
78	WAM	Composition same as WAA	Cast at UJ	Cast at 1080 deg.
79	WAN	Composition same as WAB	Cast at UJ	Cast at 1080 deg.
80	WAO	Composition same as WAC	Cast at UJ	Cast at 1080 deg.
81	WAP	Composition same as WAD	Cast at UJ	Cast at 1080 deg.
82	WAQ	Composition same as WAE	Cast at UJ	Cast at 1080 deg.
83	WAR	Composition same as WAF	Cast at UJ	Cast at 1080 deg.
84	WAS	Composition same as WAG	Cast at UJ	Cast at 1100 deg.
85	WAT	Composition same as WAI	Cast at UJ	Cast at 1100 deg.
86	WAU	Composition same as WAJ	Cast at UJ	Cast at 1100 deg.
87	WAV	Composition same as WAK	Cast at UJ	Cast at 1100 deg.
88	WAW	Composition same as WAL	Cast at UJ	Cast at 1100 deg.
89	WAX	Comp. is Cu-80, Sn-14, Pb-3, Ni-3	Cast at UJ	Cast at 1150 deg.
90	WAY	As above	Cast at UJ	Cast at 1150 deg.
91	WAZ	As above	Cast at UJ	Cast at 1150 deg.
92	WBA	As above	Cast at UJ	Cast at 1150 deg.
93	WBB	As above	Cast at UJ	Cast at 1150 deg.
94	WBC	As above	Cast at UJ	Cast at 1100 deg.
95	WBD	As above	Cast at UJ	Cast at 1100 deg.
96	WBE	As above	Cast at UJ	Cast at 1100 deg.
97	WBF	As above	Cast at UJ	Cast at 1080 deg.

No.	Sample ID	Description	Area of application	Source of sample
98	WBG	As above	Cast at UJ	Cast at 1080 deg.
99	WBH	As above	Cast at UJ	Cast at 1080 deg.
100	WBI	As above	Cast at UJ	Cast at 1080 deg.
101	WBJ	Comp. is Cu-87, Sn-11 and Pb-2	Cast at UJ	Cast at 1150 deg.
102	WBK	As above	Cast at UJ	Cast at 1150 deg.
103	WBL	As above	Cast at UJ	Cast at 1100 deg.
104	WBM	As above	Cast at UJ	Cast at 1100 deg.
105	WBN	As above	Cast at UJ	Cast at 1080 deg.
106	WBO	As above	Cast at UJ	Cast at 1080 deg.

Notes: Temperature drop on withdrawal from furnace was somewhat large for all samples cast at UJ. Observed to drop to 1,000 deg. from 1,150 deg. and to below 1,000 from 1,100 deg. Castings from WAM to WAW were essentially compositions from WAA to WAL respectively. The eleven castings were poured at a lower temperature of 1,100 deg. C compared to the first temp. of 1,150 deg. C.

7. Permanent mould design



8. Full test results as undertaken on samples

No.	Identity	Cu	Sn	Pb	Ni	Mean HV	Mean μ
1	FFA	91.0	6.68	1.36	0.18	71.7	0.42
2	FFB	86.6	6.92	4.24	0.22	91.7	-
3	FFC	86.8	8.59	0.07	0.07	128.7	0.22
4	FFD	84.9	3.94	2.77	0.43	84.2	0.21
5	FFE	86.9	6.99	0.59	0.14	83.4	0.53
6	FFF	81.4	7.47	5.88	0.35	162.2	0.28
7	FFI	84.0	5.28	2.90	0.35	84.4	-
8	FFK	79.5	6.47	15.10	0.51	106.2	0.54
9	FFL	89.7	4.56	0.25	0.16	90.0	0.19
10	FFM	86.8	0.34	0.43	0.42	73.3	0.15
11	FFN	88.1	1.13	0.30	0.17	92.2	0.62
12	FFO	83.7	1.07	0.50	0.49	78.7	0.65
13	FFR	86.3	1.39	0.08	0.02	109.4	0.41
14	FFS	95.0	0.78	0.52	0.12	84.4	0.35
15	HFA	91.4	4.48	1.21	-	104.2	0.19
16	HFB	80.0	1.57	3.03	-	118.8	0.23
17	KCA	76.5	5.46	5.78	0.45	92.4	0.46
18	MCA	83.0	6.85	0.45	-	111.1	0.18
19	MCB	87.8	8.26	0.68	-	113.2	0.27
20	MCC	77.1	4.78	9.10	-	111.2	-
21	MCD	87.6	3.90	0.47	0.10	67.6	0.42
22	MCE	79.0	5.71	0.34	0.02	84.2	0.27
23	MCF	78.2	4.64	0.53	0.01	73.3	0.35
24	MCG	88.7	0.51	0.18	0.17	73.6	0.32
25	NFA	95.7	1.76	0.22	-	227.1	-
26	NFB	98.3	0.03	0.28	-	105.8	0.37
27	HFC	75.2	9.53	6.22	0.27	120.4	0.27
28	FOI	90.5	5.01	2.46	0.21	93.7	0.4
29	FOJ	91.2	6.09	0.27	0.13	126.7	0.28
30	FOK	86.4	6.09	0.4	0.13	-	-
31	FOL	88.1	6.78	0.35	0.07	159.1	0.21
32	FOM	89.1	4.43	1.27	0.21	-	-
33	FON	79.3	6.3	0.34	0.09	101.3	0.24
34	FOP	75.5	6.26	0.25	0.1	-	-
35	FOR	86.9	5.91	1.55	0.21	101.3	0.14
36	FOU	96.0	0.99	0.49	0.02	82.9	0.28
37	HFD	75.5	6.07	9.29	0.23	108.4	0.3
38	FOO	96.1	2.03	1.05	0.08	132.6	0.2
39	FOQ	90.0	8.04	0.57	0.09	153.6	0.26
40	FOS	98.7	0.15	0.38	0.13	140.5	0.24
41	FOT	97.5	0.39	1.35	0.05	93.7	0.24

No.	Identity	Cu	Sn	Pb	Ni	Mean HV	Mean μ
42	WAA	88.3	2.7	5.82	0.2	67.8	0.24
43	WAB	83	3.14	6.04	0.22	67.8	0.2
44	WAC	76.9	6.29	11.72	0.42	72.9	0.21
45	WAD	71.1	11.16	1.43	1.7	277.9	0.34
46	WAE	74.5	9.35	2.82	2.53	166.1	0.25
47	WAF	77.6	10.61	7.8	0.87	158.3	0.2
48	WAG	74.2	13.07	7.26	1.53	118.0	0.18
49	WAI	81	11.15	2.35	1.31	138.7	0.29
50	WAJ	81.8	10.78	1.65	0.85	140.8	0.27
51	WAK	80.1	12.34	1.5	0.8	152.0	0.32
52	WAL	84.5	10.79	2.13	0.75	111.1	0.28
53	WAM	91.5	5.77	1.69	0.86	64.1	0.24
54	WAN	92.9	2.68	2.97	0.23	66.6	0.26
55	WAO	80.9	4.86	12.05	0.39	75.3	0.19
56	WAP	74.8	17.63	1.15	1.54	257.4	0.38
57	WAQ	75.9	13.04	2.95	2.44	156.8	0.27
58	WAR	68.5	16.05	5.95	0.75	162.9	0.26
59	WAS	74.5	9.83	7.62	1.39	117.9	0.16
60	WAT	77.4	9.97	2.57	1.37	124.4	0.24
61	WAU	77.3	9.85	1.46	0.85	133.6	0.3
62	WAV	82.7	11.7	1.51	0.81	148.2	0.28
63	WAW	75.1	9.94	1.94	0.62	119.5	0.24
64	WAX	79.3	8.12	5.51	3.73	139.5	0.21
65	WAY	82.7	8.28	5.52	1.98	136.7	0.21
66	WAZ	82.6	8.96	4.56	2.86	136.6	0.23
67	WBA	79.6	9.7	2.55	2.14	134.1	0.24
68	WBB	81.8	9.75	3.6	3.53	146.0	0.2
69	WBC	75.2	10.96	3.47	0.52	138.8	0.26
70	WBD	78.3	11.88	3.56	4.59	150.3	0.19
71	WBE	76.6	10.25	3.52	3.28	143.9	0.22
72	WBF	81.4	11.72	3.85	1.45	135.0	0.2
73	WBG	76.4	10.38	3.07	1.94	127.4	0.24
74	WBH	79.9	7.72	3.38	4.16	140.5	0.24
75	WBI	78.7	10.56	3.15	4.81	153.3	0.19
76	WBJ	89.4	4.94	2.09	0.17	95.5	0.28
77	WBK	87.0	4.12	2.99	0.2	91.2	0.3
78	WBL	89.8	5.89	3.26	0.07	102.5	0.22
79	WBM	81.7	6.61	4.21	0.09	94.8	0.22
80	WBN	83.7	4.62	4.46	0.09	87.2	0.14
81	WBO	83.9	3.8	2.38	0.09	85.6	0.24

Note: The following twenty one (21) samples were removed from table due to incomplete data; FFG, FFH, FFJ, FFP, FFQ, FFT, FFU, FFV, FFW, FFX, FFY, FFZ, FOA, FOB, FOC, FOD, FOE, FOF, FOG, FOH and WAH.

9. One sample t-test results for group samples by using SPSS

One – sample statistics for Laboratory Medium Temperature Casting (LMTC) Hardness

LMTC Mean hardness	N	Mean	Std. Deviation	Std. Error Mean
	10	127.390	18.9799	6.0020

One – sample test for LMTC Hardness

LMTC Mean hardness	Test Value = 85					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	7.063	9	.000	42.3900	28.813	55.967

One – sample statistics for LMTC Friction

LMTC Mean friction	N	Mean	Std. Deviation	Std. Error Mean
	10	.2330	.04111	.01300

One – sample test for LMTC Friction

LMTC Mean friction	Test Value = 0.12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	8.692	9	.000	.11300	.0836	.1424

One – sample statistics for Laboratory Low Temperature Casting (LLTC) Hardness

LLTC Mean hardness	N	Mean	Std. Deviation	Std. Error Mean
	12	126.008	55.3360	15.9741

One – sample test for LLTC Hardness

LLTC Mean hardness	Test Value = 85					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	2.567	11	.026	41.0083	5.850	76.167

One – sample statistics for LLTC Friction

LLTC Mean friction	N	Mean	Std. Deviation	Std. Error Mean
	12	.2375	.05864	.01693

One – sample test for LLTC Friction

LLTC Mean friction	Test Value = 0.12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	6.941	11	.000	.11750	.0802	.1548

One – sample statistics for Standard Hydraulic Stock (SHS) Hardness

SHS Mean hardness	N	Mean	Std. Deviation	Std. Error Mean
	12	100.308	29.7571	8.5901

One – sample test for SHS Hardness

SHS Mean hardness	Test Value = 85					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	1.782	11	.102	15.3083	-3.598	34.215

One – sample statistics for SHS Friction

SHS Mean friction	N	Mean	Std. Deviation	Std. Error Mean
	11	.2691	.11995	.03617

One – sample test for SHS Friction

SHS Mean friction	Test Value = 0.12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	4.122	10	.002	.14909	.0685	.2297

One – sample statistics for Standard Mining Stock (SMS) Hardness

SMS Mean hardness	N	Mean	Std. Deviation	Std. Error Mean
	14	108.493	38.3246	10.2427

One – sample test for SMS Hardness

SMS Mean hardness	Test Value = 85					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	2.294	13	.039	23.4929	1.365	45.621

One – sample statistics for SMS Friction

SMS Mean friction	N	Mean	Std. Deviation	Std. Error Mean
	12	.3450	.15826	.04569

One – sample test for SMS Friction

SMS Mean friction	Test Value = 0.12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	4.925	11	.000	.22500	.1244	.3256

One – sample statistics for Standard Processing Stock (SPS) Hardness

SPS Mean hardness	N	Mean	Std. Deviation	Std. Error Mean
	13	76.600	55.8112	15.4793

One – sample test for SPS Hardness

SPS Mean hardness	Test Value = 85					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	-.543	12	.597	-8.4000	-42.126	25.326

One – sample statistics for SPS Friction

SPS Mean friction	N	Mean	Std. Deviation	Std. Error Mean
	9	.3356	.10967	.03656

One – sample test for SPS Friction

SPS Mean friction	Test Value = 0.12					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the difference	
					Lower	Upper
	5.896	8	.000	.21556	.1313	.2999

10. Analysis of lubricating oil sample from Fox Foundry

ALFRED H KNIGHT (ZAMBIA) LIMITED
LUBRICANT TESTING DIVISION
ANALYSIS OF LUBRICATING OIL SAMPLE
FROM FOX FOUNDRY

REPORT NO. 17748

CHARACTERISTICS	**TEST METHOD**	**FOX FOUNDRY ENGINE OIL**	**GENERAL GUIDELINES (ISO VG 100) USED OIL**
SANAS ACCREDITED METHODS			
Specific Gravity at 15 ºC	ECM 13 (ASTM D1298)	-	-
Viscosity at 40 ºC, cSt	ECM09 (ASTM D445)	86.84	90 – 110
Viscosity at 100 ºC, cSt	ECM09 (ASTM D445)	7.79	5.6 – 9.3
Total Base Number (TBN), mgKOH/g	ECM 10 (ASTM D664)	7.44	>5
NOT SANAS ACCREDITED METHODS			
Dirt and wear Elements, ppm		ECM05 (Emission Spectrometry)	
Silicon (Dirt)		15.82	<40
Iron		55.87	<80
Copper		40.03	<50
Chromium		3.34	<30
Aluminium		9.04	<30
Lead		8.76	<50
Tin		0	<30
Viscosity Index		22	-
ISO Viscosity Grade		Approx. 100	100
Flash Point, ºC	ECM12 (ASTM D3828)	-	>180
Water Content, % Vol.	ECM07 (ASTM D95)	2%	< 0.50
COMMENT (based on the tests done)		Excess water present and low viscosity for good engine performance	-

11. Calculation of amount of energy used in melting at Fox Foundry

The workings below are based on data obtained from Fox Foundry (as indicated in Table 4.4a above) related to the periods 2014 and 2015 and assumes that the materials treated were entirely bronze conforming to the standard C93200. In addition, it is assumed that the energy source was only used diesel fuel of net calorific value of 43,400 kJ/kg. The theoretical amount of energy needed to melt a tonne of bronze is arrived as follows;

Data: Heat capacity of solid bronze (based on copper) is 380 J/kg deg.C
Heat capacity of liquid bronze is 410 J/kg deg.C
Latent heat of fusion of the alloy is 2.07×10^5 J/kg

(i) Heating the solid bronze from ambient cold temperature of 20 deg.C to its melting temperature of 1083 deg.C requires;

380 J/kg deg.C (1083 deg.C – 20 deg.C) = 4.40×10^5 J/kg ……. (a)

(ii) Add the latent heat of fusion of the melted bronze to the above;

2.07×10^5 J/kg ……..(b)

(iii) Heating the liquid bronze form 1083 deg.C to the casting temperature of 1183 deg.C;

410 J/kg deg.C (1183 deg.C – 1083 deg.C) = 0.41×10^5 J/kg ……....(c)

Adding all the results of (a), (b) and (c) will give a total theoretical energy required to melt a tonne of bronze;

6.52×10^5 J/kg (or 0.181 kWh/kg or **181 kWh/tonne** bronze melted)

In practice, the actual amount of energy used is estimated at twice the theoretical and will therefore be **362 kWh per tonne** of bronze.

	Year 2014	Year 2015
1. **Total weight of bronze cast** as given by cumulative weights during each year	28,367 kg	33,718 kg
2. **Total weight of diesel used at foundry** using volumes given in litres from purchase records (1 litre is $10^{-3}m^3$ and density is $837 kg/m^3$)	(837 kg/m^3 x 5.772m^3) 4,831.16kg	(837 kg/m^3 x 6.507m^3) 5,446.36kg
3. **Total energy equivalent of weight of diesel used at foundry** (1kg of diesel has 4.34×10^7 Joules of energy)	2.10×10^{11} *Joules*	2.36×10^{11} *Joules*
4. **Energy used per kg bronze melted** at foundry	7.39×10^6 *J/kg*	7.01×10^6 *J/kg*
5. **Energy used at foundry in kWh**	2.05 *kWh/kg* 2,053 *kWh/tonne*	1.95 *kWh/kg* 1,947 *kWh/tonne*

12. Electricity tariffs in Zambia as of 1st January 2020

ZESCO LIMITED

REVISION OF ELECTRICITY TARIFFS

In accordance with the requirements of section 8 sub-section 2 of the Electricity Act CAP 433 of the Laws of Zambia, notice is hereby given that ZESCO has revised its electricity tariffs effective 1 January 2020. The new fixed, energy, and demand charges are as given below:

		Current Tariffs	Approved Tariffs
1. METERED RESIDENTIAL TARIFFS (Capacity up to 15kVA)			
R1-Consumption up to 100kWh	Energy Charge/kWh	0.15	0.47
R2-Consumption 101 to 300kWh	Energy Charge/kWh	0.15	0.85
R3-Consumption above 300kWh	Energy Charge/kWh	0.89	1.94
Fixed Monthly Charge		18.23	-
2. COMMERCIAL TARIFFS (Capacity up to 15kVA)			
C1-Consumption up to200kWh	Energy Charge/kWh	0.54	1.07
C2- Consumption above 200kWh	Energy Charge/kWh	0.54	1.85
	Fixed Monthly Charge	96.41	-
3. SOCIAL SERVICES TARIFFS			
Schools, Hospitals, Orphanages, Churches, Water pumping, Street Lighting	Energy Charge/kWh	0.49	1.19
	Fixed Monthly Charge	83.84	203.73
4. DISTRIBUTION TARIFFS			
Purchasers of power for distribution to **retail** customers. (Exchange rate: ZMK12.411/US$)	MD Charge/kVA/Month		64.02
	Energy Charge/kWh		0.58
5. MAXIMUM DEMAND TARIFFS			
MD1-Capacity from 16kVA to 300kVA			
	MD Charge/kVA /Month	24.45	42.79
	Energy Charge/kWh	0.35	0.61
	Fixed Monthly Charge	239.44	419.02
	Off Peak MD Charge /KVA/Month	12.23	21.39
	Off Peak Energy Charge/kWh	0.26	0.46
	Peak MD Charge/KVA/Month	30.56	53.48
	Peak energy Charge/kWh	0.44	0.77

MD2-Capacity from 301kVA to 2,000kVA

MD Charge/kVA /Month	45.73	80.03
Energy Charge/kWh	0.30	0.53
Fixed Monthly Charge	478.84	837.97
Off Peak MD Charge /KVA/Month	22.87	40.01
Off Peak Energy Charge/kWh	0.23	0.39
Peak MD Charge /KVA/Month	57.16	100.03
Peak energy Charge /kWh	0.38	0.66

MD3-Capacity from 2,001kVA to 7,500kVA

MD Charge/kVA /Month	73.06	126.39
Energy Charge/kWh	0.25	0.43
Fixed Monthly Charge	1,014.55	1,755.17
Off Peak MD Charge /KVA/Month	36.53	63.20
Off Peak Energy Charge/kWh	0.19	0.32
Peak MD Charge /KVA/Month	91.33	157.99
Peak energy Charge /kWh	0.31	0.54

MD4-Capacity from 7,500kVA to 10,000kVA

MD Charge/kVA /Month	73.47	127.10
Energy Charge/kWh	0.21	0.36
Fixed Monthly Charge	2,029.13	3,510.39
Off Peak MD Charge /KVA/Month	36.74	63.55
Off Peak Energy Charge/kWh	0.16	0.27
Peak MD Charge/KVA/Month	91.84	158.88
Peak energy Charge /kWh	0.26	0.45

NOTE:

The above tariffs are:

(a) Exclusive of 3% Government excise duty

(b) Exclusive of 16% Value Added Tax (VAT)

V.M.MUNDENDE

MANAGING DIRECTOR

29 December 2019

13. Development Bank of Zambia financial access guidelines

FACILITY APPLICATION GUIDELINES

All applications for facilities should be in writing covering the following:

1. Background information on the applicant to include:

- Company name and ownership details supported by documentation; viz; certified copies of Articles of Association, Certificate of Incorporation and Certificate of shares, including a PACRA Printout
- Names of shareholders, Directors and their CVs
- Share capital indicating nominal and paid-up capital
- Full description of the business activities
- History of the company highlighting major developments, product mix and other relevant information
- Indicate Associate or subsidiary companies with details of shareholding, type of business, number of employees and audited accounts for the last three years

2. Requested facility to include:

- Amount
- Type of facility
- Purpose and tenor
- Draw-down and repayment plan

3. Key Industry information to include:

- Location of project and a description of infrastructure in place or required for the implementation of the project
- Type of raw materials required and sources for production enterprises
- Key industry players, their market share and assessment of own performance and standing compared to competitors.
- Competitive advantage vis-à-vis other players highlighting details of critical success factors
- Company's market size and share

- List of major buyers and suppliers and the terms of trade. Indicate contact persons and their contact numbers or emails
- Key risks and how they are mitigated
- Business trade cycle
- Marketing strategy

4. Management and employees' information:

- Management structure
- Key personnel, their qualifications and experience

5. Financial information to include:

- Audited financial statements for the last 3 years
- Latest Management accounts
- Your Quarterly Returns to Zambia Revenue Authority (ZRA) and Tax clearance for the current financial year
- Project cost break down and proposed means of financing
- Budgets (profit and loss, cash flow and balance sheet projections) and underlying assumptions for the duration of the loan
- Latest breakdown of Debtors and creditors, with age analysis
- Explanations should be given for any material negative or positive variances in the trading and financial information

6. Security being offered for the facility:

- Indicate type
- If property, valuation reports from Bank approved Valuers will be required upon approval of the Facility. You may indicate the estimated value based on old valuations.

7. **Present bankers.**

Full details to be provided on the following:

- Name of bankers, contact details and persons
- Facility enjoyed if any
- Security given where relevant
- Status report
- Copies of bank statements for last 12 months

8. **Environmental Impact Assessment (EIA):**

Projects with significant environmental impacts are required by law under the Environmental Impact regulations of the Environmental Council of Zambia (ECZ) to comply with the national law. Every company must check with ECZ if it is required to submit an Environmental Impact Assessment Brief (EIAB) or a full-fledged EIA study. The EIA and ECZ approval are required by the Bank as part of its internal due diligence on applicants.

9. **Know Your Customer (KYC-Required upon Facility Offer)**

Completion of Know Your Customer (KYC) formalities with the Bank, namely:

- Duly certified copies of the promoters' valid identity documents;
- Duly certified copies of their respective latest utility bills;
- Four Passport size photos each;
- Employment, residential or other such permits where applicable;

10. General Terms

The table below indicates the general terms currently being offered by the bank on its facilities:

Description	Facility	
	EUROBOND	Other
viii) Eligibility	SMEs	SMEs & Larger Companies
ix) Currency	Loans may be obtained in Zambian Kwacha and any other eligible foreign currency such as US Dollars.	
x) Loan Amount	Min: ZMW 1,000,000 Max: ZMW 5,000,000	Min: ZMW 1,000,000 Max: N/A
	The set limits also applies for equivalent loan amounts requested in foreign currency	
xi) Interest Rate		
- Zambian Kwacha	SME Base Rate (Inflation Rate) + 2%	Bank of Zambia (Policy Rate) + Risk Margin%
- Foreign Currency	12-Months Foreign Currency LIBOR + Risk Margin%	12-Months Foreign Currency LIBOR + Risk Margin%
xii) Grace Period	This will range from a minimum of 3 months to a maximum 24 months on the Principle amount, depending on the cash flow projections. There will be no grace period on Interest, unless in exceptional cases.	
xiii) Tenure (Repayment Period)	Not exceeding 7 years (84 Months)	Not exceeding 15 years (180 Months)
xiv) Fees		
- Appraisal Fee (%)	1% of the loan amount applied for (Non-refundable upfront payment)	
- Facility Fee (%)	2% of the loan amount applied for (Payable following facility approval)	
- Commitment Fee (%)	3% on undrawn balance after 90 days	

14. A guide to assist small bronze foundries towards good bearing production

Introduction

The information and materials contained in this guide arises from a number of sources that include discussions with persons operating a number of foundries both in South Africa and Zambia and references consulted during literature review for the thesis. The target foundries are those referred to as small scale under-resourced foundries (SURFs) that use only rudimentary methods and procedures to achieve output. The shop floor personnel in those facilities possess limited education and mostly at middle high school level and received no formal training in foundry practice. Through time spent at these SURFs however, the workers have acquired some experience and knowledge to enable them contribute to the production of castings.

The main objective in this guide is therefore to supplement the existing experience and knowledge of persons already working in these entities in order to equip them with the ability to deal with new situations that may arise from implementation of new technology and changing circumstances in the process of production. SURFs rely entirely on scrap metal raw materials as main production ingredient. Melting of metal is done in oil fired crucibles with little or no control over metal composition and energy losses. The output from melting is sand cast and subsequently machined either as semi or fully finished products for sale.

Modules to support objectives in this guide have been developed with this work to enhance knowledge of foundry personnel and can be offered on request at the work place or off site at a training institution as a complete package of seven (7) modules or parts of it. The duration of seven (7) days for the full course was arrived at on the basis of the South African foundry industry experience as well as guidance from the Indian Institute of Foundrymen.

Procedures to be followed

Assumptions made to go along with the steps given below include adherence to safety procedures for operating personnel and equipment and that the tasks being carried out throughout the production chain have had and continue to have reasonable success as mandated in the concerned company's goals.

(i) Selection of input raw materials

Undertake material classification based on tested compositions or on-site wet chemical analysis if available or accessible. The material can then be grouped by nature of usage. Charging to furnace can then be based on usage and that is especially helpful when there is minimal or no composition adjustment undertaken subsequently during melting.

(ii) Perform material balances for melting to achieve desired cast quality

In the event of a need to adjust composition of the known scrap metal input to suit target output, an easy to use spreadsheet programme such as the one shown below can be applied to achieve that. The three fields of available material, desired product and required weight to be added or diluted are self-explanatory and units of weight can be adjusted to suit any situation and can be used prior to or during melting.

Simple spreadsheet to work out mixing quantities for melting (Adapted from this thesis)

	Programme to determine the quantities of metals to be added							
		Copper	*Tin*	*Lead*	*Nickel*	**Total**		
Desired product in percent (%)		87.00	11.00	1.00	1.00	**100.00**		
Desired product weight (kg)		0.296	0.037	0.003	0.003	**0.340**		
Available material in percent (%)		88.00	6.80	2.80	0.20	**100.00**		
Available product weight (kg)		0.297	0.023	0.009	0.001	**0.337**		
Difference in weights of elements (kg)		-0.001	0.014	-0.006	0.003			
required to be added								

(iii) Carry out melting, casting and energy audits

Melting of copper based alloys present special problems in most furnace types especially oil fired crucibles. Prior to addition of charge materials to the furnace and during the preheating stage, a reducing chemical is charged first to the furnace to provide protection from oxidation. Considerable levels of both hydrogen and oxygen dissolve in the molten metal and lead to porosity upon solidification.

Melt as per procedure for given alloy composition and adjusting furnace atmospheric conditions to suit oxidation for hydrogen removal and a reduction atmosphere for the prevention of loss of volatile elements. De-oxidants such as phosphorus may also be used to remove residual oxygen when the level of the element is critical in specific applications.

Energy cost is a huge component in foundry processing. Whatever the source, considerable resources are used on procurement. Conservation measures must be applied whenever and wherever possible to maximise on the use energy. If electricity is used for melting, the operation should be undertaken at periods or times when utility tariffs are at their lowest in the 24 hour cycle.

(iv) On post cast treatments and machining

Undertake fettling or cleaning of castings as would be the case for a particular product. As sand casting is the main method for producing bearing bronze, metal volume and temperature at the time of casting should be targeted at producing a microstructure that ensures minimum acceptable mechanical properties. This is so because grades of bronze in this category cannot be heat treated for mechanical property enhancement for metallurgical reasons. However stress relief heat treatments are possible for maintaining casting hardness within a given range.

Leaded bronzes are naturally easy to machine and possess one of the highest machinability rates of engineering materials. When high volumes of a single bronze bearing product are required, CNC machining is the most suitable way of manufacturing them.

15. Contributions from the study

1. **"Status of the copper alloys casting sector in Zambia", Lungu C V**, Paterson A E and Masinja J H, Egycast 2019, November 8th to 11th 2019, Hurghada City, Egypt

2. "**An analysis of bronze bearing materials and castings at a foundry in Kitwe, Zambia", Lungu C V** and Paterson A E, Egycast 2017, October 27th to 30th 2017, Sharm El-Sheikh, Egypt

3. "**Viability of casting a bearing bronze using a permanent mould for a small foundry**", **Lungu C V** and Paterson A E, South African Metal Casting Conference 2017, 14th to 17th March 2017, Johannesburg, South Africa

4. "**Sustainable production of quality bronze alloy bearings in under-resourced small scale casting facilities**", Lungu C V, 7th Cross Faculty Symposium, March 2016, Wits University

5. "**Sustainable production of quality bronze alloy bearings in under-resourced small scale casting facilities**", Lungu C V, CHMT 21st Anniversary Seminar, September 2015, Wits University (Was awarded a prize for data analysis used in paper)

6. "**A Review of Casting Quality Problems and Potential Solutions in Small Scale Foundries**", Lungu C V and A E Paterson, International Journal of Scientific and Engineering Research (Vol. 2, Issue 7, Feb. 2016, ISSN 2229-5518)

7. "**Challenges encountered in production of quality bronze alloy bearings in under-resourced small scale casting facilities in Zambia – A preliminary assessment**", Lungu C V, South African Symposium on Metal Casting Technology 2014, 3rd to 4th November 2014, Cape Peninsula University of Technology, Cape Town, South Africa