

https://dspace.org/

The viability of manually producing and using concrete roof tiles for low cost housing in South Africa.

Bathke, Robert Michael

2014-03-10
http://hdl.handle.net10539/14080

Downloaded from a DSpace repository. https://dspace.org/

THE VIABILITY OF MANUALLY PRODUCING AND USING CONCRETE ROOF TILES FOR LOW COST HOUSING IN SOUTH AFRICA

ROBERT MICHAEL BATHKE

Dissertation awarded with distinction on 18 May 1999

A dissertation submitted to the faculty of Architecture, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree Master of Science in Building Management.

Johannesburg 1998

DECLARATION

I declare that this dissertation is m own, unaided work. It is submitted for the Degree of Master of Science in Building Management at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

R Bathke

Robert Michael Bathke

15 Day of December 1998

ABSTRACT

The roof is the element of a structure that provides the occupants with the greater part of the shelter they have from the elements. The roof covering is also the most exposed part of the structure and as such it not only has to offer acceptable thermal, acoustic and weather performance in order to provide the occupants with a comfortable living environment but it also has to be durable if the structure is to be considered a success.

When considering low cost houses the requirements of the roof covering are the same as those mentioned above, except that they have to be met in the most cost-effective way possible. At present the most frequently used roof covering for both formal and informal low cost housing in South Africa is galvanised steel sheeting. This choice in roof covering is a compromise, it provides a durable, easily installed and most importantly a cheap roof while providing the occupants with exceptionally harsh living conditions.

A survey conducted on the roof coverings available at this time on the South African market reveals that when selecting a roof covering for a low cost dwelling a compromise will have to be made. This is said due to the fact that none of the roof coverings surveyed satisfied all the requirements for an ideal low cost roof.

A South African company, Hydraform, has proposed introducing a system that allows individuals to manually produce low cost concrete roof tiles. This system, namely the Agri-Tile system, utilises technology similar to that used by a number of other commercial companies which have successfully produced large numbers of low cost concrete tiles used on roofs in other countries. Case studies of three of these companies revealed that these low cost roof tiles provide acceptable levels of performance while remaining relatively cheap.

Initial research into the strength and strength-gain-over-time characteristics of the Agri-Tiles (as well as the effect on the strength of the tiles when they were produced using five different fine aggregates) revealed that while this system of tile production has potential it also has a number of problems.

The potential shown by the low cost concrete tiles, the need for such a roof covering on the South African market and the general lack of information encountered on the topic of low cost concrete tiles indicated that there is a need for a thorough evaluation of this system of tile production and of the tiles themselves.

After consulting the South African Bureau of Standards and the Agrément Board of South Africa an evaluation of the tile production system, the tiles themselves and the material used to produce the tiles was undertaken using the Agri-Tile as a case study.

The evaluation revealed that only after significant modification was the Agri-Tile system capable of producing tiles which, when produced in the controlled environment of the laboratory, consistently met the strength requirements of the South African Bureau of Standards. In addition, the modifications made to the tile production system eliminated the need for prefabricated moulds, which is the most expensive item of equipment needed to produce the tiles. The quality of the tiles was still highly dependent on the workmanship used to produce them and as such no guarantee of quality will be available if the tiles are manufactured in an uncontrolled environment.

Systematically changing the grading profile of the sand used to produce the tiles revealed that the tiles may be produced from a wide range of sands with different grading profiles without compromising the strength of the tiles.

It was therefore concluded that in principal the Agri-Tile approach using the proposed moulding system and a very wide range of sands could make a contribution to the supply of low cost roofing material. However, strict control over quality would be necessary and the author doubts whether this could be achieved consistently over a wide range of building sites.

ACKNOWLEDGEMENTS

I would like to thank the following people for their invaluable help and assistance with this dissertation.

Professor John Morris (University of the Witwatersrand)
Mr J Kofahl (Hydraform)
Mr Klaus Schubert (Marley Roofing)
Mr Graham Jessop (Jessop and Associates)

Special thanks go to my parents and Jennifer Klein for their love, support and encouragement throughout my academic career.

The financial support from my parents, the G.E. Pearce research Scholarship, my FRD Bursary and the D.F Corlett Bursary are gratefully acknowledged. Without this financial support I would not have been able to undertake this research.

TABLE OF CONTENTS

DECLARATION II

ABSTRACT III

ACKNOWLEDGEMENTS V

TABLE OF CONTENTS VI

LIST OF PLATES VIII

LIST OF TABLES IX

LIST OF FLOWCHARTS IX

LIST OF GRAPHS X

1. INTRODUCTION 1

1.1 Importance of the roof 1
1.2 *Roof functions* 1
1.3 The South African situation 2

2. ALTERNATIVE ROOFING IN SOUTH AFRICA 6

2.1 The ideal roof 6
2.2 Alternative types of roofing available on the South African market 8
2.2.1 Organic roof coverings 9
2.2.2 Metallic roof coverings 12
2.2.3 Synthetic roof coverings 24
2.2.4 Mineral roof coverings 27
2.2.5 conclusion 35

3. CASE STUDIES 37

3.1 Eco Beton 37
3.2 J.P.M Parry and Associates 39
3.3 Groupo Sofonias 43
3.4 Hydraform's Agri-Tile system 46

4. PREVIOUS RESEARCH UNDERTAKEN 48

4.1 Wratten 48
4.2 Harisis 49

5. THE AGRI-TILE EVALUATION AND MODIFICATION **52**

5.1 Standards 52
5.1.1 Standards for mechanically produced concrete tiles 52
5.1.2 Standards for manually produced concrete tiles 56
5.2 The Agri-Tile evaluation 57
5.2.1 The Agri-Tile system 58
5.2.2 Laboratory production of tiles using the Agri-Tile system 61
5.2.3 Testing the Agri-Tiles 62
5.2.4 Problems encountered with the laboratory production of tiles using the Agri-Tile system 66
5.3 Modification of the Agri-Tile system 69
5.3.1 Variations in tile strength, weight and thickness 69
5.3.2 The mould issue 70

6. MATERIAL EVALUATION **77**

6.1 Cement 77
6.2 Water 79
6.3 Aggregate 81
6.3.1 Harmful substances in the aggregate 81
6.3.2 Water requirement 83
6.3.3 Grading of the aggregate 83
6.3.4 Determining the grading envelope of sand used to produce Agri-Tiles 86

7. CONCLUSION **102**

APPENDIX A: The tile average tables i

APPENDIX B: The rain penetration test rig xxii

PLATES xxv

REFERENCES xxxiv

BIBLIOGRAPHY xxxvi

LIST OF PLATES

Plate 1 xxv
Figure 1- The original Agri-Tile
Figure 2 - Moulding the original Agri-Tile

Plate 2 xxvi
Figure 1- The apparatus used to test the transverse strength of Tiles produced by Groupo Sofonias
Figure 2- The vibrating table used by Groupo Sofonias

Plate 3 xxvii
Figure 1- Examples of the high quality injection moulded polypropylene moulds used by Groupo Sofonias
Figure 2- An example of a roof covered with tiles produced by Groupo Sofonias

Plate 4 xxviii
Figure 1- The beam crusher used to establish the *transverse strength of the tiles*
Figure 2- The specially constructed rain penetration test rig

Plate 5 xxix
Figure 1- The first frame with material moulds in place
Figure 2- The second frame with material moulds in place

Plate 6 xxx
Figure 1- The clamps on the side of the frame supporting the steel sheet on which a green tile waits to be pulled onto the material mould
Figure 2- An example of the folding problem encountered with the first frame

Plate 7 xxxi
Figure 1-The various tile profiles tested
Figure 2- The new parabolic "b" profiled Agri-Tile

Plate 8 xxxii
Figure 1-The original Agri-Tiles undergo the rain penetration test
Figure 2-The modified Agri-Tiles undergo the rain penetration test

Plate 9 xxxiii
A summary of graphs 6D to 6I

LIST OF TABLES

TABLE A) Summary of the average tile thicknesses and weights 63
TABLE B) Average tile strengths 65
TABLE C) Average thicknesses and weights of the modified tile 69
TABLE D) Modified tile widths and associated strengths 72
TABLE E) The grading envelope suggested for sand by the SABS 84
TABLE F) The sand grading profiles suggested by SKAT for various tile thicknesses 85
TABLE G) A summary of the grading changes made to the profile of river sand 89

LIST OF FLOWCHARTS

FLOWCHART 1) The need for a cost effective, durable and thermally acceptable roof covering. 5
FLOWCHART 2) Alternative roofing available on the South African market 36
FLOWCHART 3) Case studies and earlier research undertaken on MCR roofing 51
FLOWCHART 4) The Agri-Tile evaluation 76

LIST OF GRAPHS

GRAPH A: The effect of the cement type on the strength of mortar 78

GRAPH B: Grading limits for sand (supplied by the Portland Cement Institute) 85

GRAPH C: The natural grading profile of river sand 87

GRAPH D: Tile strengths relative to concentrations of 4750μm particles in river sand 90

GRAPH E: Tile strengths relative to concentrations of 2360μm particles in river sand 91

GRAPH F: Tile strengths relative to concentrations of 1180μm particles in river sand 93

GRAPH G: Tile strengths relative to concentrations of 600μm particles in river sand 94

GRAPH H: Tile strengths relative to concentrations of 300μm particles in river sand 96

GRAPH I: Tile strengths relative to concentrations of 150μm particles in river sand 97

GRAPH J: The grading profiles of river and red building sand 99

1 INTRODUCTION

1.1 IMPORTANCE OF THE ROOF

"The ability of any building to fulfil the purpose for which it is intended depends on a great many considerations, but its efficiency as a dwelling house or for the purpose of manufacturing or storing goods is governed more by the qualities of its roof than by any other factor." (Blake 1945)

Blake made this comment because he feels that the roof is the element of the structure that provides the occupants with the only shelter they have from the elements, and as such, if a structure has a bad roof it will be a failure from the start. As a result he concludes that no matter how sound the foundations or strong the walls, these or any other steps taken to make a building habitable will be in vain if the roof fails in its primary task of protecting the inside of the building from the elements.[1]

1.2 ROOF FUNCTIONS

In order to understand why Blake makes the above statement it is important to understand the functions of the roof.

Briefly the roof is one of the parts of the building envelope and as such it contributes towards the thermal insulation of the structure. It helps maintain a steady temperature in the structure, which is required to keep the occupants comfortable and healthy. An even temperature is also required by structures that are built to fulfil a specific function such as hospitals, greenhouses and schools. The temperature of the roof and walls of the structure determines whether or not condensation of water vapour in the air will take place on these surfaces.[2] A roof must also be able to accommodate thermal movement associated with temperature extremes without losing its integrity.

It is essential that the roof is durable, as failure of the roof will result in frequent costly repair or the redundancy of the structure. The elements and components of a roof must be designed to have adequate structural strength so that it remains intact, stable and has limited, controlled deformation under working stresses due to dead and imposed loads. A large proportion of external noise will be transmitted into the structure if the roof does not provide adequate sound insulation giving rise to uncomfortable conditions for the occupants.

Some of the building materials used to construct roofs are flammable and as fire is a potential threat to both life and property the roof should offer a degree of fire protection to the occupants and/or owners of a structure.

Most structures go through some sort of evolution in their lifetime. In order not to impede any changes that the owners might want to make, and so reduce the potential usefulness and efficiency of the structure, the roof should offer a degree of adaptability and lend itself to modification.

The roof is one of the most exposed parts of the structure [4], and as such it should lend itself to simple cost effective maintenance so that the structure does not lose integrity due to lack of maintenance

In most cases one of the primary considerations architects and developers take into account when selecting a roof type is the cost.[3] As such no matter how successfully a roof meets the above requirements it will, in most cases, not be considered if it is too costly.

1.3 THE SOUTH AFRICAN SITUATION

The South African population is currently estimated at 38 million.[5] The unemployment rate is estimated at 30 percent of the active population at national level reaching as high as 49 percent in urban areas. An average of 49 percent of the population lives in urban areas and the annual population growth rate, measured between 1991 and 1994, was 2.1 percent representing a population growth of 150 percent within the next 20 years. The Urban foundation has estimated that the population of Gauteng will rise from the current 7.2 million to 20 million within the next 20 years, other metropolitan areas such as Durban and Cape Town are experiencing similar growth patterns.[6] This indicates a strong tendency toward urbanisation and one of the overriding socio-economic implications of rapid urbanisation is that most urban immigrants are of low-income status. The high population growth and unemployment rate combined with the congregation of the low-income class in concentrated areas has a fundamental effect on the demand for low-cost housing.[7] The Urban foundation estimated that in 1993 the housing shortage was approximately 1.8 million units, which would rise to 4.7 million units by the year 2000.[8]

The urgent need for the provision of housing is apparent. However this need for housing is not only a need for shelter, but housing also plays important socio-economic and political role in the structure of a country. Adequate housing is a prerequisite for stability, welfare and mutual understanding.[8]

At present low-cost housing in South Africa can be divided into two categories namely formal and informal low-cost housing.

The formal low-cost housing sector comprises mainly conventional houses, which are erected by commercial contractors.[8] These houses generally make use of trussed roofs covered with galvanised steel sheeting. This can be seen in the specifications for the Alpha House (the Alpha house was designed by the CSIR as an alternative approach to low cost housing) and in the specifications for the MANTAG houses (houses designed to the minimum criteria of the Agrément Board of S.A.).

Due to a lack of finance **the informal low-cost housing sector** consists to a great extent of squatter shacks, erected by the occupants, using any material available.[8] Once again galvanised steel is the most common roof covering. These informal low-cost houses attempt to copy conventional roofing, which according to Olivera 1993 has the following common repercussions:

- The roof is a replica of an original, except here inferior workmanship and materials are used to construct an ill designed roof, with the result that it is often structurally unsound and there is a poor utilisation of material
- Roofs cannot be upgraded or extended due to the lack of skilled workmanship and the ability to design the necessary alterations
- Conventional roof coverings are not necessarily aimed at making use of local resources and as such these are not always the most viable roof for the situation
- Roofing materials such as galvanised steel sheeting are manufactured outside the community, therefore money used to purchase this material leaves the community

It can be seen in the cost comparison, commissioned by the Concrete Manufacturers Association and compiled by Professor R Schloss and Dr R Nkado that currently galvanised steel is the cheapest form of roofing available. This combined with the fact that galvanised steel is relatively easy to erect has made it one of the most attractive forms of roofing material for the low cost builder.

However due to the fact that galvanised steel sheeting is a thin dense covering it has a number of disadvantages when used as a roofing material, these are:

- Poor acoustic and thermal performance
- A limited life span, particularly in coastal or highly polluted environments
- Localised corrosion resulting from abrasive cutting and nailing results in a reduced life span
- Poor quality sheeting is being imported from abroad and used in low cost housing. This results in a poor quality roof that is highly susceptible to any form of damage and as a result has a very limited life span

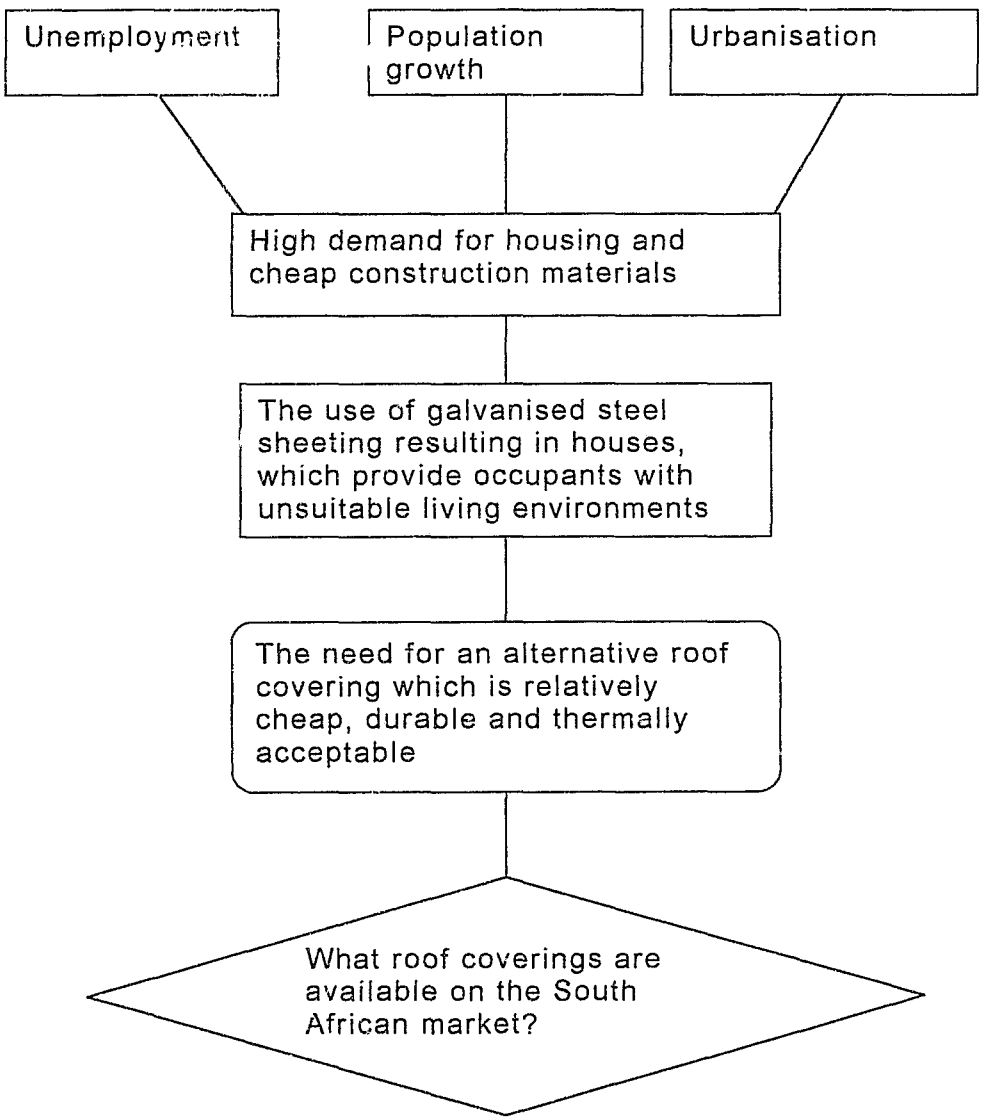
According to the Anglican priest Jeremy Platt, who lived in the informal settlement Vlakfontien which is situated south of Johannesburg "the main difficulty experienced by the homeless in erecting structures was the roof, which is complicated and time consuming to build. The roof invariably leaked and had no ceiling or insulation, this made conditions unbearable in temperature extremes".[7]

In conclusion the rapid population growth, urbanisation and high rate of unemployment present in South Africa have all contributed to a high demand for low-cost housing and cheap construction materials. At present the roofing requirements of the low-income section of the community are being fulfilled by the use of galvanised steel sheeting. In the light of the compelling opening statements by Blake and the above quotation from Jeremy Platt it can be seen that using galvanised steel as a roof covering could compromise the integrity of the entire house. In fact in a report conducted by The Institute for Race Relations in 1975 M H Hubbord, J Humphrey and V Domingo state that during a survey of the residents of four squatter settlements around Cape Town it was found that some of the main complaints made by residents about their houses were related to the roofs. Complaints such as leaking roofs and houses which were too cold and unhealthy were common.

As a result the author felt that a roof covering which is relatively cheap, durable and thermally acceptable, which utilises local material and labour thereby improving the cash economy of the community is required as an alternative to galvanised steel sheeting.

In order to establish whether such a roof covering is available in South Africa a survey of the various roof coverings available on the South African market will be reported in chapter 2 of this thesis.

Flow chart 1: The need for a cost effective, durable and thermally acceptable roof covering



2 ALTERNATIVE ROOFING IN SOUTH AFRICA

2.1 THE IDEAL ROOF

From the introduction it is clear that there is not only an urgent demand for low-cost housing in South Africa but there is also a need to find a suitable type of roof covering to be used on these structures. However, before assessing the various types of roof coverings available on the South African market, it is important to establish the requirements for the roof of a low-cost structure. The introduction to this thesis touched on the requirements for a roof of a general-purpose structure and this will be expanded on here with special emphasis being placed on the requirements for the roof of a low-cost dwelling.

Cost

In terms of low cost housing the cost of the roof will in all likelihood be the single most important factor considered by the prospective homeowner. No matter how well the roof meets the rest of the requirements placed on it, it will not be considered if it is too expensive. A roof designed with the low-income section of the community in mind must therefor be at least as cheap as the cheapest alternative or face the possibility of being overlooked for the cheaper alternative no matter how the performance characteristics of the two roofs compare.

Maintenance

The initial cost plus repair and maintenance costs of the roof during the life of the structure should not cause it to be more expensive in total than any alternatives or the initial cost saving will be in vain.

Durability

The roof is the most exposed part of the structure[4]. Due to the position of the roof it receives more direct and prolonged exposure to the forces of nature than the other components of the structure, such as the walls do, and as such it should resist damage caused by wind, rain, hail, frost and live and dead loads during the lifetime of the structure.

Weather resistance

The main function of a structure is to protect the occupants from the elements. One of the main functions of the building envelope, of which the roof is a major part, is to contribute towards the achievement of a reasonably steady temperature. An even temperature is required to ensure the comfort of the occupants or for the specific function of the structure. Water vapour in the air condenses when it comes into contact with a roof that is below the dew point temperature.[2] Water droplets that form can cause deterioration of roof timbers as well as unhealthy conditions for occupants. As a result it is preferable that the roof remains above dew point temperature. Due to financial constraints it is not envisaged that additional insulation or waterproofing will be used to supplement the performance of low-cost structures. The roof must therefore provide the occupants of the structure with as much protection as possible from the elements of nature to ensure comfortable, healthy living conditions. From the introduction it can be seen that failure of the roof will result in the failure of the structure as a whole. The roof must also be able to accommodate thermal movement due to the extremes in temperature to which it is subjected without losing its integrity.

Strength and stability

As with all structures the structural elements and components of the roof of a low cost house must be designed for adequate strength to remain intact, stable and with limited, controlled deformation under working stresses due to dead and imposed loads.

Sound insulation

The noise level in the environment in which a structure is built can have a significant impact on its internal living environment as a large portion of external noise will be transmitted into the structure if the roof does not provide adequate sound insulation and this may result in uncomfortable conditions for the occupants. This will be emphasised in a low-cost structure which has no additional sound insulating material such as a suspended ceiling.

Fire protection

Fire is a potential threat to both life and property and the roof should offer a degree of fire protection to the occupants and/or owners of a structure. If the materials composing the roof are flammable they may ignite due to exposure to intense radiant heat and flame from fires in adjacent buildings or, alternatively, due to burning material carried on rising hot air which may lodge on roof coverings. This is especially true in low-cost housing where houses are often built very close to one another and where people rely on open fires and paraffin stoves for heating and cooking.

Adaptability and modification
Most but especially low-cost structures go through some sort of evolution in their lifetime. In order not to impede any changes that the owners might want to make, and so reduce the potential usefulness and efficiency of the structure, the roof should offer a degree of adaptability and lend itself to modification.

2.2 Alternative types of roofing available on the South African market

Having established that the requirements for the ideal low-cost roof covering are:

- Low cost
- Infrequent and inexpensive maintenance
- Durability
- Weather resistance
- Strength and stability
- Sound insulation
- Fire protection
- Adaptability and modification

it is important to evaluate the various roof coverings available on the South African market and to ascertain how well these roof coverings meet the above requirements.

The information for the evaluation was obtained from a number of local companies but, due to the variation in quality of product produced by different companies only those companies which are the leaders in the local industry were included in the survey. During this survey it became apparent that there is a distinct lack of technical information available from manufacturers of roof coverings. The information that is available is difficult to interpret and use for the purpose of comparisons due to the wide range of tests, units and standards used to determine the information.

The roofing available on the South African market can be divided into four categories, namely organic, metallic, synthetic and mineral roof coverings.

2.2.1 ORGANIC ROOF COVERINGS

THATCH

The thatching available in South Africa can be divided into two classes, commercial and traditional.

Commercial Thatch

There are a large number of commercial thatchers in South Africa and, as thatching is as much a craft as a product, it is apparent that the quality of roof produced will vary from company to company. For this reason the author used information supplied by Letaba Thatchers who claim to be the largest thatching company in the Southern Hemisphere.

Cost
Thatch is more expensive than conventional roofing such as concrete tiles, fibre cement and galvanised steel sheeting. This is compounded by the fact that thatched roofs have a steep pitch requiring additional material, are heavy, which means they require additional timber support and it is required that lightning conductors must be installed next to thatch roofs to reduce fire hazards. Thatchers claim this cost is offset by the gain in usable areas (ie dormer windows and a mezzanine level) that accompany a thatched roof. On average thatch will cost approximately R180 per square metre of roof area. Thatch can be insured, but insurance companies charge a premium of between 20% and 30%, judging each case on individual merit.

Maintenance
All Letaba roofs are maintained for a period of 5 years, free of charge (excluding storm damage). After this a roof should be serviced at 10 to 12 year intervals. A thatched roof's natural life span is 35 years after which a 70mm to 100mm layer of new thatch should be placed over the existing roof.

Durability
Properly laid thatch can last in excess of 35 years.

Performance

Thermal
No thermal resistance calculations have been conducted on South African thatch. Experience has however shown that, due to the large number of air voids within the thatch grass, it has excellent thermal insulation properties.[2]

Acoustic
Thatch provides superior acoustic insulation to both airborne and impact noise when compared to most roof coverings partly due to the fact that grass is placed in heavy, dense compacted bundles.[9]

Strength and stability
Thatched roofs utilise rugged construction methods and material. The timber (which is obtained from Eucalyptus trees) has a high resistance to stress compared to softwood. Rafters are spaced at a maximum of 700mm centres, joints in the rafters are spiked with 150mm to 200mm nails and bolted at the main stress points. Main stress points are the main tie beams, collar ties, scissor braces, ceiling joints etc. Bolt sizes vary from 12mm to 24mm in diameter.

The grass used is the Hyparrhenia species. It is hand cut and only straight pieces are used. The grass varies between 760 and 1020mm long and the thickness of the thick ends of the grass varies between 1.8 to 4mm thick. Cape Thatching Reeds are used if specially requested by a customer. It is preferable to use grass in the same climate as that where it originates as opposed to moving it to foreign conditions that will cause it to deteriorate more quickly.

Fire protection
Fire resistant blankets made from substances such as sisalation, Burlington cloth or hessian soaked in a cement gypsum slurry are used to reduce the risk of fire in thatch roofs. Sisalation is the most commonly used in South Africa. It is installed underneath the thatch and allows a very slight airflow which prevents a high humidity from building up in the thatch which can result in the growth of fungi and bacteria. The CSIR has tested and approved the fire rating of Letaba thatch.

Advantages
- Thatch is aesthetically pleasing.
- Thatched roofs have a potentially large usable roof space.
- Thatched roofs have good thermal and acoustic performances

Disadvantages
- Thatching is a trade and not a product. As such there is a large discrepancy in performance of roofs installed by different companies. Letaba and a few (approximately 6) other thatchers have formed the Master Thatchers Association of South Africa to improve the image of thatching and protect the consumer against poor workmanship. However very few thatchers have joined and a large number of small thatchers are still working on a very informal basis, producing a poor quality product which is tarnishing the reputation of the South African thatching industry.[9]

- Lightning conductors are required which increases cost.
- Repair and maintenance is expensive.
- Maintenance is required.
- The additional layer of 70mm to 100mm of thatch placed over the existing roof every 10 to 12 years, as part of the maintenance of the roof, places an additional load on the load bearing walls and supporting timber roof structure.
- Insurance premiums are high.
- Fire hazard is greater than in standard construction methods.

Traditional thatch

Traditional thatch is mostly used by the indigenous population in rural areas. It is a craft, passed from generation to generation, which is gradually being lost as people move to urban areas and other building material is substituted for thatch. As with commercial thatch the quality of the product is largely dependent on the skill of the craftsman. There is therefore a large variation in the quality of roofs produced.

As land is bought and access to it is restricted the local availability of suitable roofing materials for use by the rural communities is becoming more scarce.

Cost
Thatched roofs of rural houses are often cheap. The labour used to construct the houses is supplied by those who intend inhabiting the house and the building materials used are collected from the surrounding area. The durability and maintenance of the roofs will be determined by the quality of the workmanship and material used in the construction of the roofs.

Performance

Thermal
The thermal and acoustic performance of traditional thatch is high when compared to other roofing material. However this is once again dependent on the thickness and quality of the roof covering and the skill of the thatcher.

Strength and stability
As with the thermal and acoustic performance, the strength and stability of the traditional thatch roof will depend on the quality of material and workmanship which goes into the roof and, as such, will vary from roof to roof.

Fire protection
Traditional thatch roofs offer very little protection from fire. No fire blankets or fire retardant chemicals are used and these roofs are potential fire hazards.

Advantages

- A cheap, effective roof
- Good thermal and acoustic properties.
- Material can be obtained from the environment
- Labour is supplied by the potential occupants or by the community

Disadvantages

- Skilled thatchers from the indigenous population are becoming fewer.
- Material for thatching is more difficult to obtain as land is fenced off and access is restricted.
- Regular maintenance is required.
- There is a high risk of fire associated with traditional thatch especially where houses are constructed close together.
- The quality of the roof is highly dependent on the quality of the material gathered and the workmanship supplied by the occupants, causing the quality of the roofs to vary significantly.

2.2.2 METALLIC ROOF COVERINGS

PRESSED METAL TILES

A South African company, Harveytile, produce pressed metal tiles from metal blanks produced by Iscor. The metal blanks are galvanised and form a substrate which is profiled and then subjected to a phosphate treatment before being coated with a 100% acrylic coat on both sides, (this further inhibits rust). Stone granules are then applied along with another acrylic coat before the tile is cured in an oven. Harveytile produce 3 profiles of which only one, the Academytile, can be used within 10km of the coast. The Academytile uses a special high performance substrate from Iscor that has 60% more galvanising than a conventional Harveytile.

Installation
It should be noted that Harveytile produce a comprehensive range of sundries including facias, ridges, bargeboards, flashings, hips, valleys and nails. Harveytiles are easily installed provided a few basic rules are followed.

Trusses to be used are standard lightweight 114x38mm trusses spaced at 1100mm. Battens are 38x38mm, spaced at 369mm centres. The roof pitch should be between 15 and 45 degrees if no underlay is used. According to Harveytile roof pitches of between 10 to 15 and 45 to 90 degrees require an underlay.

Tiling should start from the bottom and proceed upward, however if this is not possible you can start at the top and work your way down. Laps should face away from rainwater discharges onto the roof.

Nailing should be done through the top weather protected surfaces, using 40-50mm serrated Harveytile nails. Nail heads must be touched up with Harveytile touch up paint (to hide the nail and to prevent rust). Cut edges of tiles and accessories must also be touched up in this way.

Cost
Cost will vary depending on the quantity of tiles the customer is ordering. For small quantities of tiles customers should go to Cashbuild who are the main distributors for Harveytile. For medium to large projects customers can go directly to Harveytile. An approximate cost per square metre of erected roof area would be R170.00. Insurance companies view a Harveytile roof as a roof constructed using standard building methods and as such insurance premiums for this type of roof are standard.

Maintenance
The manufacturer claims that no maintenance of a Harveytile roof is required.

Durability
While no approximate life span can be provided for Harveytile roofs, as the first roofs erected are still in use, the company offers a 30 year guarantee on the metal substrate and a 15 year guarantee on the coating.

Performance

Thermal
On the 5th of April 1994 Harveytiles were tested in accordance with SABS Test 722/85 206/MA 27.[3] This was a comparative test incorporating a room with various roofs which were subjected to

an external temperature of 35^{0}C for 16 hours. After this time the following internal room temperatures were observed:

IBR profile galvanised steel sheeting	29.3 ^{0}C
Concrete roof tiles	27.1 ^{0}C
Asbestos cement sheeting	27.6 ^{0}C
Harveytile	28.7 ^{0}C

This indicates that thermally Harveytile has superior performance to normal galvanised steel sheeting, but does not perform as well as concrete roof tiles or asbestos cement sheeting.

Acoustic
The acoustic performance of Harveytile was compared to that of galvanised steel sheeting and concrete roof tiles using SABS Test 717/85/61 conducted on the 13th of December 1995. The findings were that Harveytile outperformed the steel sheeting but did not perform as well as concrete roof tiles. However both Harveytiles and concrete tiles were within acceptable limits (The advantage of concrete tiles was a larger mass, but they had larger gaps between tiles which impaired their performance).[3]

Rain resistance
Harveytile carries the SABS cyclone certificate as well as the French equivalent certificate and this enables this product to be used on islands such as Mauritius. The manufacturer claims that Harveytile is leak proof.

Strength and stability
Harveytile carries the SABS stamp of approval and its production conforms to the SABS 0157 quality management system listing as well as to SABS ISO 9002. The entire Harveytile system holds Agrément Certificate 87/174.[3]

Fire
Harveytile passed SABS Test DIN 4102 part 7 which means it is regarded as non combustible.[3]

Advantages

- Lightweight [low transport, handling, timber support costs]
- Easy, quick and cheap installation
- Nailed in position [not easily removed by thieves or wind]
- Extensively tested [extensive technical data available]
- Versatile [pitch 10-90 degrees]
- Proven track record
- Coating guaranteed for 15 years, substrate guaranteed for 30 years
- Full range of accessories available

Disadvantages

- Thermal & acoustic performances are inferior to those of concrete tiles
- Steel tiles will eventually corrode
- Shaketiles and Elitetiles (two of the profiles produced by Harveytile) can rust if used within 10km of the coast (the use of these profiles in such close proximity to the coast would be against the manufacturer's specifications, as Academytiles are designed for this application)
- When walking on a Harveytile roof a person should walk in the valleys if walking up the roof, or along the battens if walking along the roof. Failure to do this could result in dents.
- Careless or negligent roofers might not cover cut edges of tiles or nail heads with touch up paint which will result in rust and the premature failure of the roof.

GALVANISED STEEL SHEETING

Iscor

Iscor produces a large proportion of the steel used for roofing in South Africa and the majority of the companies which profile steel roof sheeting use Iscor's products most, if not all of the time. Large holding companies such as Baldwins Steel, which is comprised of companies such as Brownbuilt, HH Robertson, Longtile and Vetco Engineering, do from time to time import steel for the manufacture of roof sheeting. However this is the exception and not the rule.

For roofing purposes Iscor produces two main products namely galvanised steel sheeting and Chromadek, which is pre-painted galvanised steel sheet. These two products will be dealt with separately. Iscor produces roofing steel, they do not profile their own range of roof sheeting. Most companies producing profiled roof sheeting not only use Iscor's products but also use the technical specifications provided by Iscor for their roof sheeting regardless of the end profile produced. Having said that, all of the information supplied by Iscor will apply to all of the roofing produced by the manufacturers of profiled steel roof sheeting using Iscor's products.

Hot dip galvanised cold rolled steel sheets

It should be noted that Iscor provide a wide range of this product both in grade and coating. While Iscor recommend certain zinc coating and substrate thicknesses for specific applications it is the profiling companies who decide which specification of steel they will use to produce their roof sheeting.

Gauge
Cold rolled: 0,4mm to 2,0mm

Selection of the thickness and type of steel substrate is based on structural and mechanical requirements. Two types of steel substrate can be ordered forming grades that are more ductile, which are used for general roofing applications, or structural grades that are used where the application calls for a more rigid sheet. Sheets ranging between 0.4 and 0.8mm thick are recommended for roofing. The list below gives the sheet thicknesses and the various widths and finishes in which they are available.

Thickness(mm)	Width(mm) Regular spangle	Width(mm) Minimised spangle
0,4	600-1200	600-1175
0,45	600-1265	600-1175
0,5	600-1330	600-1175
0,6	600-1330	600-1175
0,8	600-1330	600-1175

Coating - specification for manufacture

Galvanised sheet is produced on continuous zinc coating lines to the requirements of BS 2989, ASTM A924 & A653 and SABS 934. The galvanising process yields an evenly zinc coated sheet with a bright, smooth, metallic finish. The finish can be supplied with a normal or a minimised spangle finish. Zinc coatings of different thicknesses can be supplied to suit specific end-use requirements. The thickness of the zinc coating is selected according to the corrosion resistant life expectancy required. (BS-British Standard, ASTM-American Standard for Testing Material).

For roofing purposes galvanised coatings from Z 275 up are recommended. Z 275 indicates zinc coating with a normal thickness of 19 micro metres and, using the triple shot test, 275 grams of zinc per metre. The triple shot test is carried out by measuring the zinc coating at three locations on the galvanised sheet.

Bonding and coating
To ensure good adhesion of zinc to the substrate, bond tests and impact adhesion cupping tests are performed on all products irrespective of specification. The impact test is severe and indicates possible adhesion problems well in advance. Coated sheet bond test specimens are required to bend 180^0 in any direction without the coat flaking on the outside bend only.

Zinc coating surface finish

A zinc coated surface finish has a metallic lustre as the result of an unrestricted growth of zinc crystals during normal solidification. Variations in the size and brightness of spangles are possible depending on the galvanising process and conditions, but this has no effect on the quality and corrosion resistance of the coating. Normal spangle is supplied for a wide range of products where over-painting is done at a later stage for maintenance purposes.

Flattened Minimised Spangle

This coating is obtained by restricting normal zinc crystal growth by spraying the sheets with a liquid, which is composed of a special blend of chemicals and between 60% and 70% water, as it emerges from the zinc tank. It offers improved flexibility. This finish is recommended for applications where high gloss paint is required.

Painting

Chemical conversion coatings and primers have been developed to provide good adhesion of subsequent paint films to the galvanising.

Cost

A large number of companies buy Iscor's galvanised steel sheeting, profile it and then resell it. The cost of the profiled galvanised steel sheeting varies according to the profile and gauge of the sheet and from company to company. Costs range between R120 and R200 per square metre of roofing area installed. Insurance premiums are standard as this roof covering is regarded as standard construction practice.

Maintenance

Galvanised sheeting should be painted before signs of red corrosion appear.

Durability

Under normal conditions the zinc coating is consumed gradually through atmospheric corrosion. Obviously the profile of the end product will impact on life span by creating micro climatic conditions (such as overlaps from which trapped water cannot escape). The following table reflects generally accepted exposure periods in years for typical coatings in different environments before red corrosion might be visible on 5% of the sheets' surface.

Coating designation	Years in rural environment	Years in industrial environment	Years in marine environment
Z 275	15-25	10-20	=<1
Z 450	25-40	15-20	5-8
Z 600	40-60	20-25	8-12

Performance

The general performance of profiled galvanised steel sheeting is influenced by the profile of the sheeting as different profiles have different water shedding capabilities, which inturn influence the pitch of the roof. The profile of the sheet will also influence the micro climatic conditions created at construction details such as overlaps and the methods used to fix the sheeting to the timber or steel structure of the roof, all of which impact on the strength, durability, weather performance and cost of the roof.

There are however a large number of different profiles available some of which are highly specialised. The specialised sheets are designed to improve fixing methods (the sheets are clipped together) or the insulation properties of the roof. The specialised sheets are more expensive and as such are not suitable for low cost roofs. The performance characteristics discussed below are those of the simpler, cheaper profiles.

Thermal and acoustic

Iscor has not established either the thermal or the acoustic performances of the galvanised steel sheeting that they produce. Due to the light, thin, dense, highly conductive nature of this roof covering it is generally seen as having very poor thermal and acoustic properties. This was substantiated by the tests conducted by Harveytile, which were discussed in section 2.2.2 of this chapter.

Strength and stability

One of the advantages of a steel roof is its strength and stability. The large number of joints unavoidable with many other types of roof coverings can be almost completely eliminated by using profiled steel sheets that extend from the ridge of the roof to the end of the eaves thus avoiding head laps completely. Metallic coverings are not brittle, as are mineral coverings, and are not easily worn down by attrition. As this type of covering can be manipulated with ease it can be fixed so securely that the sheets are prevented from being torn off by high winds or from suffering any form of mechanical injury from rough usage.[1]

Fire
Refer to Chromadek

Advantages

- lightweight [low transport, handling and timber support costs]
- easy, quick and cheap installation
- nailed in position [not easily removed by thieves or wind]
- versatile [pitch 5-90 degrees]
- proven track record

Disadvantages

- Cutting: Cut edges of galvanised sheet less than 1,6mm thick are adequately protected by the cathodic action of zinc coating (it is pulled down by the guillotine blade or scissors and this covers the edge of the substrate). However nailing and abrasive cutting with grinders can reduce the protection offered to the substrate by the zinc coating which in turn could result in premature localised corrosion.

- Strain ageing: Strain ageing refers to the fact that the steel sheets become less ductile as they age resulting in surface markings from stretcher strain (Luders lines) or fluting when the sheet is formed. It is recommended that the period between the final processing of the galvanised steel sheeting at the mill and the profiling of the sheeting is kept to a minimum to prevent the occurrence of strain ageing. This period should preferably not exceed 6 weeks.

- Wet storage corrosion: Under normal wet and dry conditions a protective zinc oxide/zinc carbonate layer naturally forms on exposed surface, which improves its resistance to corrosion. The protective nature of these coatings may be seriously impaired when exposed to wet conditions for extended periods in the absence of air. This condition is characterised by a white deposit referred to as white rust.

- Thermal & acoustic performance is poor due to the material's high conductivity.

- For long life the roof design should exclude construction details which give rise to localised corrosion such as open eaves at the coast, which allow the accumulation of corrosive salts on the under side of the sheeting giving rise to localised corrosion

- Thin sheets are easily dented and distorted
- Aggressive environments significantly reduce the life span
- The narrow gap between overlapping sheets draws moisture through capillary action and also retains the moisture for long periods resulting in white rust and premature corrosion

CHROMADEK

Chromadek is a cold rolled steel sheet that is galvanised before two coats of specially formulated paint are applied on a modern continuous paint line. Iscor's painting process involves the thorough chemical cleaning and preparation of the galvanised surfaces of the sheet, followed by the application of an epoxy primer coat to both sides of the sheet. This primer coat is oven cured after which the final coat of polyester is applied, usually to one side of the sheets and similarly oven cured.

Chromadek is available with steel substrates of different grades depending on the end user's requirements. Different paint systems are also available depending on the end user's requirements. End uses are grouped into 2 main categories, namely:

1) Interior applications (which will not be covered here)
2) Exterior applications (such as roofs)

Exterior environments

Iscor uses four different environmental classifications:

1. Environments where corrosion is not severe but additional corrosion protection is required, such as typical non-polluted Highveld areas where the unprotected undersides of roof overhangs may present a problem

2. Mildly corrosive industrial or marine conditions (5 to 15km from the coast). Here a standard backing coat of half a coat of polyester 12-16 micrometres thick should be applied to the front of the sheet, over the epoxy primer, with a full coat of polyester 20-24 micrometres thick applied to the reverse side of the sheet.

3 Aggressive industrial conditions with a high incidence of pollution or aggressive marine conditions (1-5km from the coast). Here a galvanised substrate should be coated with a full coat of silicone polyester or new polyester on both sides.

4 Chromadek should not be used at a distance of less than 1km from the coast

Standards of manufacture
As discussed under galvanised sheeting Iscor's galvanising process meets SABS, BS and ASTM standards. Iscor's paints meet SABS 1091 and BS 38K standards, while the paint system properties meet the ASTM standards.

Installation
Installation depends on the end product. Fastening systems can include the likes of: rivets, self tapping screws, bolts, spring clips, wire staples, cliplock as well as various seaming methods such as lock and box seaming.

Corrosion resistance
Chromadek is intended for use under rural, mildly polluted or moderate marine conditions. Best results can be obtained through correct application, and good workmanship and maintenance procedures. Within 10km of the coast and especially areas subject to rain followed by long periods of high relative humidity certain design factors must be addressed:

- The use of full length sheets is recommended as overlapped ends can result in premature corrosion. If overlaps are inevitable, effective waterproofing and sealing is essential.
- Fasteners used for fixing must be protected to avoid corrosion.
- Sheltered areas such as the underside of roof overhangs, canopy type roofs and loading bay canopies are ideal locations for accelerated corrosion from the "under-side up" in corrosive environments. Even when not facing the sea, sea salts tend to collect in these locations as they are not periodically washed off by rain. Designers should avoid designs that will permit the accumulation of salt deposits or must provide adequate protection. A full paint coat on the reverse side of the sheet is recommended.

Cost
Chromadek costs between 20 and 30 percent per m^2 more than conventional galvanised steel sheeting of the same profile.

Maintenance
The life span of Chromadek can be extended by periodically washing painted surfaces with a mild water and detergent solution to prevent the build up of corrosive deposits. Scratches can be touched up with specifically formulated touch up paint. Re-painting will be required after between 15 and 20 years

Durability
Chromadek will require re-painting after a period of between 15 and 20 years. If Chromadek is not re-painted the zinc galvanising will begin to corrode at the rate discussed earlier in this chapter.

Thermal and acoustic
The thermal and acoustic performances of Chromadek are the same as those of galvanised steel sheeting.

Strength and stability
The strength and stability characteristics exhibited by Chromadek are the same as those of galvanised steel sheeting discussed earlier in this chapter.

Fire performance
Iscor determined the fire rating and smoke development properties of five different coatings on steel sheet metal. The indices of basic fire properties - namely flame spread, heat contribution and smoke development - of each coating were established in a tunnel oven. Possible fire spread was investigated where the coating was on the side that was not exposed to fire. Specific optimal densities of the smoke released were established when the coatings were exposed to radiant heat and flames. Tests were conducted according to ASTM specifications. Results showed that all the coatings were within the required limits and none of the coatings propagated fire spread. Smoke development was very low, too low to make any contribution to smoke development in the case of a real fire.

Advantages

- lightweight [low transport, handling, timber support costs]
- easy, quick and cheap installation
- nailed in position [not easily removed by thieves or wind]
- versatile [pitch 5-90 degrees]
- proven track record

Disadvantages

- For long life the roof design should exclude construction details which give rise to localised corrosion such as open eaves at the coast, which allow the accumulation of corrosive salts on the under side of the sheeting giving rise to localised corrosion
- Abrasive cutting and trimming should be avoided as this could lead to premature corrosion
- Although compatible with most materials, water run off from Cor-Ten, lead or copper products will stain the paint.
- Wet storage damage can occur if coils or packs are wet, resulting in prolonged exposure to moisture without oxygen
- comparatively poor thermal and acoustic performance

Other products

Chromaprep is similar to Chromadek except that the galvanised substrate is only coated with a chromate rich epoxy based primer which is suitable for over-coating with most locally available finishing paints.

Chromadek Hyplas was first produced during November 1996. It is a new product that is specifically designed for use in highly corrosive environments. It carries a warranty and has superior resistance to chemical attack, damage and abrasion, as well as excellent flexibility. Hyplas is a fourth generation plastisol that combines the inherent benefits of plastisol (mechanical, performance, corrosion, damage, abrasion and chemical resistance) with very good performance in ultra violet light. This level of performance is better than any other available coating.

ALUMINIUM, COPPER, AND STAINLESS STEEL

Aluminium, copper and stainless steel roofing is available in South Africa however these roof coverings are exceptionally expensive and only used at a clients request. They are thus not suitable for the low cost market and will not be evaluated.[3]

2.2.3 SYNTHETIC ROOF COVERINGS

POLYCARBONATE AND GLASS FIBRE REINFORCED POLYESTER SHEETING

Modek is arguably the largest fibreglass sheeting manufacturer in the country. Modek has technology agreements with companies in the United States and Europe so that it has access to the latest technology. It produces translucent roof sheet profiles in both polycarbonate and glass fibre reinforced polyester (GRP). Both of these mediums are used to take advantage of natural light and can be used in conjunction with a number of profiled steel roof sheets. GRP and polycarbonate sheets will be dealt with separately. It should be noted that this type of roofing would only be used by people wishing to take advantage of natural light. These sheets are used in conjunction with profiled steel sheeting (The GRP or Polycarbonate sheets are produced in profiles corresponding to those of profiled steel roof sheets).

GLASS FIBRE REINFORCED POLYESTER (GRP)

Cost
The approximate price per square metre of uninstalled roof sheeting varies between R60,00 and R155,00 including VAT and depending on profile and grade.

Maintenance
GRP is maintenance free.

Durability
GRP can last up to 15 years with normal use.

Performance

Thermal
The thermal conductivity of clear GRP sheeting is 0.145 W/mk. Modek 030 sheets transmit less heat than conventional clear GRP sheets (37,5% less heat than conventional clear GRP)

Acoustic
Modek have not established the acoustic performance criteria of the GRP sheeting that they produce.

Strength and stability

Tensile strength - 72MPa (minimum)
Flexural strength - 140MPa (minimum, depending on the profile of the sheet)
Shear strength - 70MPa (minimum)
Operating temperature - 20 to 80 °C, unaffected by frost and not brittle at low temperatures

Fire
Modek have not established the fire related performance criteria of the GRP sheeting that they produce.

Specifications for manufacture
All industrial profile sheets are manufactured to SABS 1150/1984 standard. This means that a high grade polyester resin is applied to the weathering surface, this prevents fibres from being exposed during the natural life span of the product.

Advantages

- Takes advantage of natural light
- Lightweight (low transport, handling and timber support costs)
- Easy, quick and cheap to install
- When nailed in position they are not easily removed by thieves or wind
- Versatile (pitch 1-90 degrees)
- Resistant to chemical attack
- Tough
- Compatible with all building material
- Modek sheets are corrosion resistant and resist attack from most chemicals, both domestic and industrial, and are recommended for environments were these conditions are present.

Disadvantages

- Spans exceeding 9m must be of heavy industrial quality
- Expensive
- Fairly short life span

POLYCARBONATE SHEETING

Cost
The approximate price per square metre of uninstalled roof sheeting varies between R122,00 to R200,25 including VAT

Maintenance
The only maintenance required by polycarbonate sheeting is an occasional wash with soapy solution.

Durability
Polycarbonate sheeting should last up to 20 years with normal use.

Performance

Thermal
Thermal conductivity - 0,21 W/mk

Acoustic
Modek have not established the acoustic performance criteria of the polycarbonate sheeting that they produce.

Strength and stability
Tensile strength - 65N/mm2
Flexural strength - 80N/mm2 (depending on the profile of the sheeting)

Specification for manufacture
The sheeting is extruded using a sheeting grade of polycarbonate that has a co-extruded weathering surface layer of UV grade polycarbonate polymer of at least 35 microns thick.

Fire
Modek polycarbonate sheeting is self extinguishing. It will not promote or assist the spread of fire and it is suitable for all glazing applications.

Advantages

- Takes advantage of natural light
- Lightweight (low transport, handling and timber support costs)
- Easy, quick and cheap installation
- Nailed in position (not easily removed by thieves or wind)
- Versatile (pitch 1-90 degrees)
- Does not transmit UV rays
- High impact resistance

Disadvantages

- Not chemically resistant to petrol, benzene, acetone, phenols, petroleum based paints or carbon tetrachloride
- Not tolerant of the plasticizer in PVC materials (including sealants and washers)
- Not scratch resistant
- When cleaned scratches can occur due to dust, etc

2.2.4 MINERAL ROOF COVERINGS

NATURAL MINERAL COVERINGS

SLATE

Mazista are the South African agents for slate and supplied the information used in this section. Mazista uses two systems of installing slate, the conventional system and the Alumaz system.

The conventional system

The conventional system has been used for years all over the world and all traditional slate roofing is installed in this manner. It is however a heavy system, resulting in a product that weighs 78kg/m^2 of roof area when using Mazista slate - a substantial timber structure is thus required. This system incorporates extensive overlapping of the slate tiles (tiles sit 3 deep on battens). The minimum roof pitch that can be used when installing the conventional system is 30 degrees.

The Alumaz system

This system of slate installation was developed to reduce the weight of the roof encountered when using the conventional system and to facilitate the construction of roofs with pitches as low as 17 degrees. The system works by reducing the slate overlap and using another material to achieve water tightness. With this system a layer of bitumen impregnated roofing felt (which is protected from the sun by a layer of aluminium foil) is used beneath the layers of slate to achieve water tightness. This system reduces the weight of the roof to 43kg/m2 of roof area.

Cost

The cost of both systems is the same per metre squared of roof area. However, while the conventional system is expensive in terms of slate and timber, the Alumaz system uses an expensive underlay that makes it more or less equal in cost to the conventional system before labour. To calculate the amount of slate needed to cover a roof using the conventional system the roof area should be multiplied by 2,5 plus 10% for cutting and breakage. To convert the roof area of a building into the quantity of slate required to cover the roof using the Alumaz system the roof area must be multiplied by 1,5 plus 10% for cutting and breakage. To calculate the amount of underlay required in 20m rolls the roof area must be divided by 3,7. The cost of a square metre of roofing varies between R210,00 and R240,00 making this one of the most expensive forms of roofing available. A slate roof falls within the parameters of the insurance industry's definition of a standard construction material, and as such insurance premiums will be unaffected by the fact that a structure has a slate roof.

Maintenance
Slate roofs require no maintenance.

Durability
No information is available on the durability of a Mazista slate roof. While poor slate may begin to decay after only a few months good quality slate can last for as long as 400 years. [2] Mazista slate should provide a durable roof, as it is SABS approved.

Performance

Thermal and acoustic
Mazista have no information on the thermal and acoustic performances of their slate. However, due to the weight of this roof covering, its sound insulating properties should be excellent. While slate is a dense material, the multiple layer construction and associated air spaces, along with experience, has demonstrated that a slate roof has good thermal insulating properties similar to other mineral roof coverings.

Strength and stability
As with other mineral coverings slate is brittle and susceptible to mechanical damage.[3]

Fire
Slate is not combustible but the increase in the quantity of timber required to support the extra weight of slate will provide more combustible fuel in the occurrence of a fire.

Advantages

- Aesthetically pleasing
- Good thermal and acoustic performances
- Long life span

Disadvantages

- Heavy (transport, installation and timber support costs are high)
- Installation is difficult, labour intensive and time consuming
- Brittle and prone to mechanical damage

MANUFACTURED MINERAL COVERINGS

FIBRE CEMENT SHEETING

Everite has been in existence for over 50 years and their fibre-cement profiled sheets and elements have a longstanding tradition of involvement in the building industry. Due to fact that they are market leaders and have a long history of involvement in the building industry, Everite was considered a suitable source of information for this thesis. The versatility of fibre-cement sheets and elements as well as the extensive range of fittings make it possible to create a solution to any roofing problem. Everite supply a number of different fibre-cement products, usually in a natural grey colour. Specially shaped sections are available on special order. For aesthetic reasons Everite suggest that the natural grey product be painted with Colorbrite paint (a water based acrylic paint) which was specially formulated for use on fibre-cement products and has a life expectancy in excess of 10 years.

Profiles

Big Six Corrugated sheets: These are the first sheets produced by Everite and have been used successfully for over 50 years on both domestic and commercial projects. These sheets are 6 mm thick. If Big Six profile sheets are used for roofs with a pitch of less than 10 degrees the end laps should be sealed. These sheets are bolted into position onto steel or timber roof structures. The maximum purlin spacing in the roof structure is 1400 mm.

Canadian pattern sheets: This profile is generally associated with housing and has clean lines and is aesthetically pleasing. These sheets are 6 mm thick. As with the Big Six profile, the end laps of Canadian pattern sheets should be sealed if used on a roof with a pitch of less than 10 degrees, this profile can be used on roofs with pitches as low as 5 degrees. These sheets are bolted to the purlins, which can be spaced at a maximum of 1400mm centres.

Span 2 and 3 sheets: Both deep profiles that create a bold look and define shadow lines creating an aesthetically pleasing roof. The longer lengths and increased spans make these products ideal for commercial and industrial projects. These sheets are designed to accommodate an overlay of clay or concrete tiles on low pitched roofs where a tile roof is required by local authorities. Span 2 is a 6mm thick sheet which is bolted to purlins spaced at a maximum of 2000mm centres, while Span 3 is 7mm thick sheet for which purlins can be spaced at a maximum 3000mm centres. Both sheet profiles can be used on roofs with pitches as low as 2 degrees.

Modulite elements: This profile is especially suitable for low, mono-pitch roofs and on structures such as carports, covered walkways and other low rise structures where a greater spanning property is a specific need. These 7mm thick sheets are bolted to purlins spaced at a maximum of 3500mm centres and can be used for roofs with pitches as low as 2 degrees.

Canalite elements: This is a deep trough like profile which has long spanning capabilities. In private residences, with near flat roofs, roof structures other than wall plates can be eliminated. This profile can support most types of suspended ceilings. It can also be used where vast expanses of virtually flat roofing, that must be supported only at the ends, are required. The use of this profile reduces the cost of the sub-structure. These 8mm thick sheets can be supported at maximum intervals of 6000mm, and can accommodate pitches as low as 2 degrees.

Victorian profile sheet: Designed to recreate the appearance of a traditional Victorian style roof it is particularly suitable for coastal application where corrosive conditions prevent the use of many other products. The sheets are 4.5mm thick and must be supported on purlins spaced at a maximum of 450mm for roof pitches of up to 35 degrees. Roof pitches of over 35 degrees allow the maximum purlin spacing to be increased to 600mm. These sheets are held in position with bolts.

Cost
The cost of uninstalled fibre cement sheets varies between R35,00 and R85,00 per square metre of roofing, depending on the profile of the sheet. Fibre cement is seen as a standard construction material by the insurance industry and as such the use of fibre cement as a roof covering will not affect insurance premiums.

Maintenance
Fibre cement roofs require no maintenance. They will however need repainting every 10 years for aesthetic purposes.

Durability
Everite give no specific information on the durability of their product. They do however say that they have roofs that have been standing for well over 40 years.

Performance

Thermal
All Everite's fibre cement profiles have a thermal conductivity of 0,35 W/m °C when tested in accordance with ASTM C518.

Acoustic
No information is available on the acoustic performance of Everite's fibre cement sheeting.

Strength and stability
Everite manufacture a number of different sheet profiles, each for a different purpose and as such the sheets are not all manufactured to the same standard. The following figures are true for all but the Victorian profile:

Density (g/cm3)	1,36	BS 4624-81
Breaking load (KN/m)	3,82	SABS 685 1985

The figures for the Victorian profile are:

Density (g/cm3)	1,26	BS 4624-81
Breaking load(KN/m)	1,46	BS 690-73 & BS 4604-81

Fire
Everite fibre cement has a horizontal fire resistance of 35 minutes in accordance with SABS 0177-11. No information is available on its performance as a roof sheeting.

Advantages

- Lightweight (low transport, handling and timber support costs)
- Bolted in position and thus not easily removed by thieves or wind
- Extensively tested (extensive technical data available)
- Versatile (pitch 2-90 degrees)
- Proven track record
- Full range of accessories
- Curved sheets and purpose made articles are available

Disadvantages

- Asbestos is a health hazard and therefore special tools are required for cutting and drilling to prevent labourers from inhaling harmful asbestos dust
- If the wings of the long spanning profiles are not stitched (joined together) the day they are laid, sagging can occur
- Nuts of fixing bolts can be over-tightened causing sheets to crack
- Sheets need to be mitred at adjacent corners to prevent overlaps four sheets thick
- Sheets are fairly brittle and susceptible to mechanical damage
- Available in grey only and repainting will be required every 10 years
- Specialist installation is recommended for large spans

CONCRETE TILES

Commercially produced concrete tiles

Watson Tile has a proven track record of over 40 years experience in the roof tile industry, and produce one of the largest range of profiles in the country. As one of the leading concrete roof tile manufacturers in South Africa, Watson Tile was used as a reliable source of information on concrete roof tiles and the concrete roof tile market in South Africa. Concrete roof tiles are manufactured using basic raw materials such as washed graded sand, portland cement, pigments and water. The tiles are extruded under high pressure resulting in a product of consistently high quality and with a strength which increases with age.

Installation

Recommended spacing of the 38 x 38mm battens is 320mm for all tiles. Rafters should be spaced at 760mm centers. An underlay is mandatory for all roofs with pitches ranging from the 17.5

minimum to 26 degrees. Watson recommend that roofs with a pitch of 26 degrees or more still use an underlay. Tiles can be nailed, clipped, nailed and clipped, or simply placed in position. A detailed discussion of the installation requirements can be viewed in chapter 5 on page 55 of this thesis.

Cost
The cost of commercially produced concrete tiles varies between R116,00 and R200,00 per square metre of installed roof area, depending on the distance from the building site to the factory as well as the profile and finish of the tile required.

Maintenance
Concrete tiles require no maintenance. They can be repainted for aesthetic purposes if the need arises.

Durability
Watson tiles have been on roofs for in excess of 48 years.

Performance

Thermal and acoustic
Watson has no specific test information on the thermal or acoustic performance of their tiles. It is however widely accepted that roofs covered with concrete tiles offer excellent thermal and acoustic properties, this is highlighted by the comparative test carried out by Harveytile is discussed in section 2.2.2, Metallic roof coverings, of this thesis.

Standard of manufacture
Watson tiles along with all the other concrete tile manufacturers who are members of the Concrete Manufacturers Association produce tiles, which not only meet but exceed the specification of SABS 542.

Fire
Concrete tiles are not flammable and pose no additional fire risk to a structure.

Advantages

- Large range of colours and profiles
- Excellent acoustic and thermal performance
- Proven track record
- Full range of accessories
- Suitable for use in highly corrosive environments
- Long life span

Disadvantages

- Efflorescence may affect tiles between 3 months and 2 years old
- Fairly heavy [high transport, handling and timber support costs]
- Roof access by thieves is easy, quick and quiet
- Limited pitch range of between 17.5^0 and 45^0
- Installation is time consuming and requires skilled workmen
- Repainting may be required for some tiles

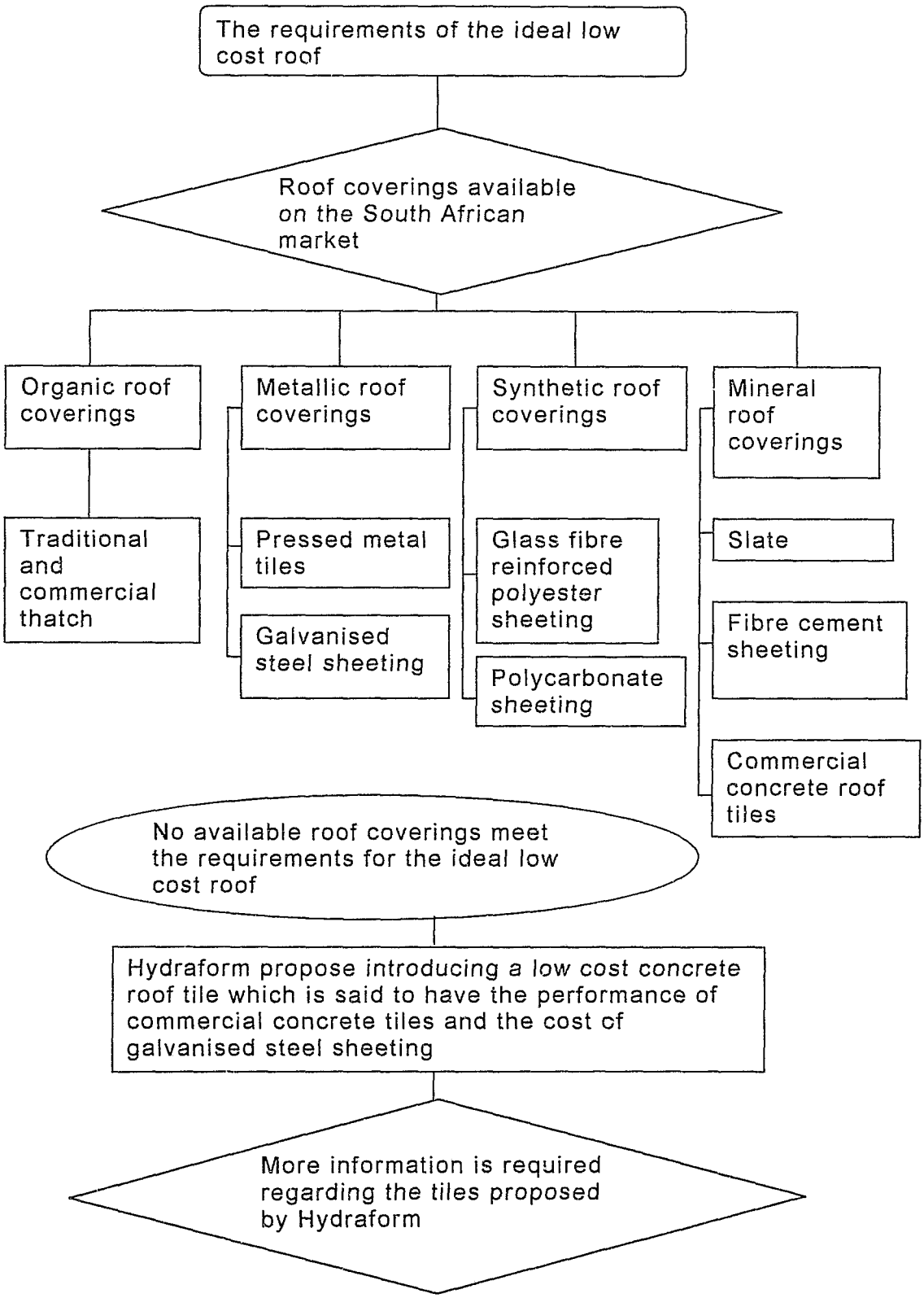
CONCLUSION

The introduction to this thesis not only highlighted the need for housing in South Africa, but also the need for more economic ways of producing these structures. As discussed one of the main problems with existing low-cost structures is the compromise made when selecting a roof covering. At present the most commonly used roof covering is galvanised steel sheeting which is known not only for its low cost and ease of installation but also for the harsh living environment provided for structure occupants due to its poor thermal performance.

The survey of the roof coverings available on the South African market conducted in this chapter revealed that while there are roof coverings which provide superior living environments to that provided by galvanised steel sheeting, they are more expensive.

A South African company, Hydraform, has proposed introducing a low cost version of the concrete roof tile, the Agri-Tile, to fill this need in the market. As with conventional concrete tiles these low cost tiles are produced from sand and cement, and as such should provide a living environment with similar characteristics to those experienced when using commercially produced concrete tiles. As no alternative to galvanised steel sheeting has been found on the local market, the introduction of Hydraform's Agri-Tile should be welcomed. However, little or no information is available on Agri-Tiles. A case study of three companies that produce similar low cost concrete tiles, known as micro concrete roof tiles (MCR) which are claimed to provide an acceptable alternative to roofing problems in other countries, is conducted in chapter 3. The study was conducted in an attempt establish whether it is in fact a potential solution to one aspect of South Africa's housing problems.

FLOW CHART 2: Alternative roofing available on the South African market



3.CASE STUDIES

3.1 ECO BETON CONCRETE ROOF TILES: MALAWI

HISTORY

Eco Systems is a commercial company which is based in Malawi. This company has been producing concrete roof tiles and roof tile making machinery since 1986. The original tiles and tile making machines were made according to designs produced by the Malawi Government's rural housing projects staff, these designs were in turn based on age-old Northern European designs. Whereas the European tiles were always fired clay tiles, the Eco-Beton tiles are made from micro concrete, which is a mixture of small quarry stones, sand and cement. Due to the nature of the concrete the tile can be much larger and manufactured more accurately than the old clay tiles.

The tiles and tile making machinery were then developed further, in several stages, before they reached their current form. Eco-Beton feels that in this form they are able to offer reliable and long lasting tiles as well as tile producing machinery.[20]

TILES

Material

The tiles are designed in such a way that they can be made of mortar or concrete and moulded without the inclusion of fibres. Typical mixes for tiles are:

Tile	Cheap tile	High quality tile
Cement	1	1
River sand	2.5	
Quarry dust (or fine sharp sand)		1
Quarry stone (3-4mm in size or similar pebble)		2.5

Tile Manufacture

In brief Eco-Beton tiles are made from cement mortar or micro concrete. The tiles are produced on manually operated vibrating tables. The vibrating table is covered with a plastic sheet that is clamped in position by a moulding frame. Mortar is placed on the plastic sheet and trowelled into position while the handle of the

vibrating table is turned. The thickness of the moulding frame determines the thickness of the tile as mortar is added until the top of the green tile is level with the top of the moulding frame. The tile is vibrated for between 30 and 60 seconds to ensure that any air trapped in the green tile is expelled. The moulding frame is then lifted and the green tile (on the plastic sheet) is transferred onto a mould.

The tiles remain on the mould for 24 hours while they cure. While on the moulds they are covered with wet hessian cloth and a plastic sheet to increase the humidity at their surface and thus prevent shrinkage cracks forming in the tile. After the 24-hour period the tiles are removed from the moulds and placed in a curing tank for a further 7 days while further strength development takes place. After 7 days the tiles are removed from the curing tank and once dry are ready for use.

In order to keep the initial capital cost of their tile producing system low Eco-Beton has limited the number of pre-formed moulds supplied with each system. The user of this system expected to produce concrete moulds in the same way tiles are produced. The only difference is that the moulding frame used to produce moulds is a plain rectangle, while the frame use to produce tiles has insets that create mitres in the tiles. The mitres avoid the problem of having an overlap 4 tiles thick at the corners when the tiles are laid on the roof.

Quality control

Eco-Beton recommends that random tiles be thoroughly inspected for physical defects. The inspection is conducted by:

A. Visually inspecting the tile for shrinkage cracks, pinholes and an excess of small air pockets. The tile should also be inspected for rough edges, warping and non-uniform thickness.
B. Using the "potters ping" test to detect hairline cracks in the tile which are too small to see. This involves holding the tile up with one hand while hitting it with a stone with the other hand. If the tile produces a clear sound it is crack free. A dull sound is an indication that cracks are present.
C. The tiles should be weighed and a variation of not more that 10% of the average tile weight is deemed acceptable.
D. The permeability of the tiles is checked by placing a tile face-up on 2 level supports. The ends of the trough formed by the profile of the tile are then blocked off with clay and the trough is filled with water. After a 2 hour period no free water should be seen hanging or dripping from the bottom of the tile. The tile may become dark in colour due to saturation.

E. The strength of the tiles is checked by supporting a tile on 2 wooden bearers each placed at a distance of one sixth of the tile length from the edge of the tile, so that the distance separating the two bearers is equal to two thirds of the tile length. A third bearer, placed in the centre of the tile, supports a drum which is filled with water. The third bearer imposes the load generated by the water-filled drum onto the tile. The load required to break the tile is then calculated and must not be less than a prescribed load.

Performance
In terms of performance Eco-Beton tiles have survived on roofs in Malawi since 1986 and have provided residents with waterproof, thermally insulating roofs of reasonable quality.

Installation
Eco Beton recommend that their tiles are installed on roofs with a pitch of 26.5 degrees. The tiles are laid in the same way one would lay commercial concrete tiles. Due to the light weight of these tiles only a light timber roof structure is required and trusses can be spaced at a maximum of 1200mm centre to centre. The size of the Eco Beton tiles allows a maximum purlin spacing of 530 mm centre to centre. The tiles are fixed to the timber roof structure with wire hooks made from 2mm thick galvanised steel binding wire.

3.2 J P M PARRY AND ASSOCIATES

British company J P M Parry and Associates Ltd can be seen as one of the international leaders in the production of low cost, small scale roofing equipment. All of the information on J.P.M Parry and Associates and the tiles and tile manufacturing plants they produce was obtained from trade literature supplied by Parry.

HISTORY

Parry's involvement in the roofing industry started in 1976 with a workshop in which the research and development of low-cost, small scale, import saving forms of roofing were discussed.
Research institutes had already had success in reinforcing concrete with artificial fibres and in .977 Parry made their first roofing sheet. The sheet was 2 metres long, reinforced with glass fibres and was produced using a hand tamping method. After this Parry started researching the possibility of reinforcing concrete using natural fibres.

In 1978 field trials by Parry revealed that the 2 metre sheets were too large and that a sheet which was 1 metre long would be more practical and could still be easily installed. Technical problems encountered in 1979 indicated that equipment used to produce roofing products had to be well made and backed by good technical services in order for a project to be successful. At this point a number of Parry's associates withdrew their resources from this roofing project.

1981 saw Parry begin researching mechanical vibration instead of hand tamping. In 1982 the first fibre cement pan tile roof was built in Cradley Heath and it was in this year that Parry set up a field research facility in Kenya. By 1983 the development of a mechanical vibrator with a simple screeding machine and plastic tile moulds was complete and the first two plants were established in Nigeria and Kenya.

Ten new tile producing plants were sold to various countries in 1984 and, together with Birmingham Polytechnic, Parry set up courses to meet the need for personnel training in construction in developing countries. The 100th mini tile plant was made and dispatched in 1985. This was also the year during which John Parry published a textbook on the research and development his company had conducted and the technology they were using. By the end of 1986 a number of special tiles for detailing work had been developed, as well as the plastic moulds for producing them. Other developments included a mortar-measuring scoop, batching boxes and quality control equipment.

A hand powered version of the vibrating table was developed during 1987 and seven of these machines were produced and distributed around the world for testing. New tile handling equipment was designed and humidity curing technology was applied for the first time. Parry introduced Multi-vibe, a detachable mechanical vibrator, which would enable tile producers to diversify into producing other Parry products which included concrete blocks, pipes, floor tiles, and elements for water tank construction.

1988 saw Parry roof tiles surviving hurricane Gilbert in Jamaica. Other development included the manufacture of a semi-sheet (a roof sheet with small dimensions) for roofing, for which the first plant was manufactured and sent to Zambia. Parry also began experiments in which fine gravel was substituted for fibres in the mortar used to produce roof tiles. In 1989 Parry tiles were supplied for a project of 1700 houses in Nairobi and fourteen plants worked night and day to supply the 2 million tiles required for the project. At this point Parry estimated that they had more than 25 million tiles on roofs world-wide.

A thousand tile plants had been produced by 1990 and they are now used in 60 countries. The Fast Moulding Unit was developed in 1991 to meet the needs of large producers. A tile can now be made every 30 seconds at less than half the cost of tiles made by conventional press-extruded systems.

TILES

Raw materials

Unlike corrugated iron and fibre cement Parry light weight roofing tiles can be made using cement and locally available raw materials, in other words sand, fine gravel and vegetable fibres. Ordinary building sand can be used. River sand will always be suitable for tile production and the fibres for fibre reinforced tiles should also be readily available. Typical examples are sisal, palm nut, coconut coir and jute. The requirement is simply for a flexible, fairly fine fibre that is not contaminated by oil or sugar.

Suggested mixes for fibre reinforced and micro concrete tiles

	Fibre reinforced tiles	Micro concrete tiles
Cement	25%	25%
Sand	75%	25%
Fine gravel	0	50%
Fibre content	0.5% by weight	0

Tile production

Parry tiles are produced on a vibrating table that has an external power source. A plastic sheet is placed on the vibrating table and a frame is clamped over the plastic sheet. The mortar is placed on the plastic sheet and is trowelled into position while the table provides vibration to assist the mortar flow and compaction. The green tile is then transferred, on the plastic sheet, to a mould. The moulds stack on top of one another covering the previously made green tiles and providing a high humidity in which the tiles can cure without suffering from shrinkage or drying cracks. After a week the tiles are ready for use.

Quality control

According to Parry good quality is vital for successful tile production. In order to produce a good quality tile Parry manufactures their tile producing equipment to very high standards. Parry uses a transverse strength test and an impact test to determine the quality of their tiles. The transverse strength test utilises a frame, which supports the tile at each end. A load is then imposed on the centre of the tile using a specially cut section of wood which ensures that the load is distributed over the whole profile of the tile. The impact test involves dropping a steel ball from a prescribed distance to determine whether the impact resistance of the tiles is greater than a prescribed value.

Durability

As far as durability is concerned Parry tiles (both micro cement and fibre reinforced) have been on roofs for over ten years and show no signs of deterioration. Accelerated ageing tests conducted in the United Kingdom show that lightweight Parry tiles do not become porous or brittle with time. The tiles are unaffected by pollution or salt spray. In Jamaica Parry tiles survived hurricane Gilbert in 1988 and in Bangladesh it is claimed that Parry tiles survived severe storms and were unaffected by 8mm hailstones.

Performance

Parry claims that it's lightweight pan tiles provide excellent thermal performance keeping the inside of the structure cool even during tropical summers. The tiles are claimed to transmit only one hundredth of the amount of heat transmitted by conventional steel sheeting and this not only improves the living conditions within the structure but also reduces heating and cooling costs. Tiled roofs are quieter. Unlike steel sheeting, tiles will absorb the noise of raindrops hitting the roof so a heavy storm will be less intrusive on the occupants of the building. The tiles hook securely to the roof structure and can also be nailed down directly to the roof battens or through wire loops moulded into the tiles. This ensures that the tiles will remain securely fastened even during exceptionally strong gusts of wind.

Cost

Parry claims that their fibre cement and micro concrete tiles can be produced with very low costs resulting in roofs are that cheaper than those erected with asbestos cement or conventionally extruded concrete tiles. They also claim that the cost of Parry tile roofs, when the tiles are produced commercially, is similar to that of corrugated iron roofs and the light weight of the tiles means that the cost of the supporting timber roof structure will be similar that used to support corrugated steel sheet roofs.

3.3 GROUPO SOFONIAS

HISTORY

Groupo Sofonias is a commercial company based in Latin America. It was born in the seventies in an adobe program which utilised sun baked clay bricks as a cheap alternative to fired clay bricks for walling. After 15 years in the industry (during which time soil construction was constantly utilised) they felt that there were many alternative innovative methods of constructing walls. These methods improved the weather performance of the structure while reducing its cost. Yet after all that time there was no universal and simple solution to the roofing problems they encountered.

That changed recently when they began experimenting with fibre cement sheets that were produced by hand. While experiences with the fibre cement sheets were not always positive Groupo Sofonias persisted with their use, as they had no viable alternative. Internationally there were mixed feelings about the fibre cement sheets although in the beginning the Latin American experience was positive. However after 3 years there were many negative sentiments about the sheets due to their poor performance. Within this time sheets had suffered cracking due to wind action and the deformation of the supporting timber structure.

In 1983 the technology seemed condemned. A critical analysis of the situation revealed that basically there were two problems affecting this product.

1. The sheets were large and had to be reduced in size.
2. The quality of the equipment used to produce the sheets had to be improved.

In 1984 the first micro concrete roof tile producing machine began to operate in Latin America. The machine was developed in England and addressed all the concerns that Groupo Sofonias had about the fibre sheets. The technology was a success and as of 1988 it is regarded as a commercial success.

The roofing advisory service of SKAT (Swiss Centre for Applied Technology) promoted a series of seminars in Switzerland that brought together experts from many countries to discuss the different aspects of the technology. Manuals have been developed for making tiles, quality control and establishment of norms, organisation of workshops, and others. SKAT continues to co-ordinate this advisory service and delegated the same task to Groupo Sofonias in Latin America.

Groupo Sofonias has introduced this technology to a number of countries. Honduras, Guatemala, Ecuador, Peru, El Salvador and Costa Rica have all been exposed to Micro Concrete Roof Tiles (MCR) successfully.

Most recently Ecosouth, a division of Groupo Sofonias, introduced micro concrete roof tiles to Namibia. A number of people from the local community have been trained to produce micro concrete tiles in two workshops established there (one in Windhoek and one in Otjiwarongo) and three show houses have been erected using micro concrete roofing. However the local community has not yet accepted the technology.[19]

TILES

Material

Groupo Sofonias use sand and cement to produce tiles. They do not use fibres for the production of tiles. A fairly strict technical procedure is used to determine the correct mix proportions for the mortar that will be used to produce tiles. They recommend that the following requirements are met to ensure that the mortar is acceptable for tile production:

1. The sand used should fall within the following grading profile:

Particle size (mm)	Percentage of sand volume particle size occupies
5-2.0	30-50
2-0.5	15-40
< 0.5	15-40

1. The water to cement ratio should range between 0.5 and 0.6.
2. The volumetric relationship of cement to sand should be 1:2.75

Production

Tiles are produced in a similar manner to Parry tiles. The tiles are produced on vibrating tables with an external power source (see figure 2 on plate 2 for illustration). Mortar is placed on a plastic sheet that covers the vibrating table. With the aid of vibration the mortar is moved into position using a trowel, the vibration also expels air entrapped in the tile and so doing ensures maximum density in the tile. A nib is formed on the tile using a small box mould attached to the vibrating table and a wire insert is placed in the nib to facilitate the fastening of the tile to the timber roof structure at a later stage. The vibration lasts for approximately one minute. An illustration of the test frame can be seen in figure 1 on plate 2.

The green tile is then transferred from the vibrating table to a high quality injection moulded polypropylene mould (see figure 1 on plate 3 for an illustration of the mould). The moulds are stacked one on top of another, thus forming an air-tight curing chamber in which the tiles can cure. The tiles spend 24 hours in the mould after which they are removed from the mould and placed in a curing tank for a further 7 days following which they are removed and allowed to cure for a further 14 days in a shady location. The tiles are then ready for use.

Quality Control

As with Eco-Beton, Groupo Sofonias has a number of tests that are applied to ensure that the tiles they produce are of an acceptable standard. The tests recommended are as follows:

1. The pore and crack test. Each tile should be visually inspected for pores and cracks. Tiles are not acceptable if cracks are longer than 5mm, surface pores deeper than 2mm and wider than 5mm.

2. The ring test. All tiles should be tapped with a coin or a stone. The tiles are rejected if a dull sound is heard as this indicates that the tile is cracked.

3. The bend test. This test is used to check the flexural strength of the tiles and 1% of the tiles should be tested in this way. The test requires the tile to be supported on 2 bearers placed 175mm either side of a centre line across the tile. A third bearer that consists of a wooden section cut to the same profile as the tile is placed in the centre of the tile and is held in place by a steel frame. The frame has a lever pivoting on a hinge and the centre of the lever rests on the third bearer. A weight is suspended from the lever and this load is transferred to the tile via the third bearer (see figure 1 on plate 2 for an illustration of the frame). A 5mm rubber strip placed between the tile and the third bearer ensures an even distribution of the load. The thickness of the test tiles will determine the weight that the tile must support. The weights that the various thickness tiles should bear are as follows: 6mm - 30kg, 8mm - 50kg and 10mm - 80kg. The test is conducted with 2 tiles and if one of the tiles fails the remainder of that batch of tiles must be left to cure for a further 14 days and then be re-tested.

4. The nib test. This test ensures that the nib of the tile is firmly connected to the tile. 1% of the tiles produced should be subjected to this test. The tile must bear a weight of 20 kg hung from the nib. If the test tile fails others should be tested

as well. If those tiles fail the batch must be cured for a further 14 days before being re-tested.

5. The permeability test. Two small weirs are formed, from mortar or clay, at the ends of the trough of the profile of the tile. The tile is supported at the ends and the trough is filled with water. No free water may have formed at the bottom outside surface of the tile after 24 hours. The test must be conducted in a relative humidity of 70% or over.

6. The weight test. Tile weight may not differ by more than 10% from that of the average tile.

Performance

Groupo Sofonias estimate that more than 10 000 000 square metres of micro concrete roofing have been erected through out the world and in Latin America alone it is estimated that there are over 8 000 000 square metres of roofing. In Nicaragua there has been ample experience with high winds which resulted in the provision of an additional piece of wire to attach the tile to the roof. Tiles fixed in this way survived not only high winds but in 1989 they survived hurricane Gilbert. Figure 2 on plate 3 shows an example of a roof produced by Groupo Sofonias.

3.4 HYDRAFORM'S AGRI-TILE SYSTEM

At the time of writing this thesis Hydraform was the only company considering introducing micro concrete tiles to South Africa. Hydraform's tile, the Agri-Tile, is loosely based on the Eco-Beton micro concrete tiles. Very few Agri-Tiles have been produced by Hydraform at this point and as such little historical and performance related information is available on them. However because of the similarity between the Agri-Tiles and Eco-Beton tiles, the Agri-Tiles are expected to have similar performance characteristics to those of the Eco-Beton tiles discussed earlier in this chapter.

Hydraform's approach to micro-concrete tiles is different from those of the other three companies studied in this chapter. These three companies establish workshops in a fixed location with permanent buildings and curing tanks and the surrounding communities are then supplied from these centres.

Hydraform, on the other hand, intends supplying the Agri-Tile machine to entrepreneurs who will travel from site to site supplying each building project with the tiles they require before moving on. This is deemed necessary due to the transport costs involved as well as to breakage's resulting from moving tiles from

workshops to surrounding communities. This would be exceptionally difficult in rural areas where a community is usually widely dispersed.

Hydraform's objective with the "Agri-tile" machine is to promote a self-help approach to the construction of low cost housing. They state that the Agri-tile machine will accomplish this as it has the following advantages over roofing systems presently used in South Africa:

1) Its use will bring up to a 60% cost saving
2) It is environment friendly and simple to use
3) Full use is made of unskilled labour from the community
4) Use is made of material usually present at or close to the building site
5) The tiles are produced on site
6) The tiles have superior acoustic and thermal properties to steel sheeting which is frequently used at present

CONCLUSION

The case studies of the three established companies, Eco-Beton, Parry and Groupo Sofonias indicate that micro concrete tiles produced using low technology equipment similar to that provided by Hydraform have provided a cheap reliable roof covering with acceptable levels of thermal and acoustic performance in a number of countries. The tiles have proved themselves historically, having provided effective shelter for occupants during severe storms.

Hydraform's attempt to introduce micro concrete tiles to South Africa should be welcomed as these tiles could provide an alternative to galvanised sheet roofing as indicated in the introduction. Alternative, low cost roofing is needed in South Africa.

The study of the various types of roofing available on the South African market, conducted in chapter 2, indicates that at the moment there is no other viable alternative to galvanised roof sheeting. In his 1996 discourse Wilton Wratten investigated the possibility of producing a low cost cement mortar roof tile using the Agri-Tile system. Wratten's research is important as it provides the only technical information on the Agri-Tile system that is available to date.

4 PREVIOUS RESEARCH UNDERTAKEN

4.1 Wratten

In 1996 Wilton Wratten produced an undergraduate discourse titled "The Production of a Viable Cement Mortar Roof Tile". The purpose of this discourse was to examine ways of improving the strength of Agri-tiles without unduly complicating the manufacturing process, since this would have defeated the intentions of Hydraform, the designers of the Agri-tile machine. Wratten examined the effect on the strength and strength-gain-over-time characteristics of the tiles when:

a) The tiles were damp cured for different periods of time.
b) The tiles were cured at different temperatures.
c) The cement to water ratio of the mortar used to produce the tiles was varied.
d) Five different fine aggregates were used to produce the tiles.

The process of tile manufacture was also examined to ensure familiarity with the operation of the machine and to identify potential problems. Wratten encountered the following problems:

1) The green tiles would break when they were transferred from the vibrating table to the mould.
2) The green tiles could be incorrectly aligned on the mould resulting in distortions in tile shape.
3) The tiles were not of uniform thickness.
4) One tile out of every batch of three tiles showed a significant strength variation.

During his research he showed that when produced under laboratory conditions Agri-Tiles can meet the strength requirements of the SABS. He concluded that dolomite sand would produce better results than the river sand used at present, and also made the following recommendations:

1) A cost comparison should be undertaken to establish the effect of using dolomite sand and rapid hardening cement instead of river sand and ordinary Portland cement (OPC).

2) That further investigation be undertaken to establish the effect of changing the thickness, dimensions and shape of the tile

3) That further investigation be conducted to establish the feasibility of adding fibres to the mortar.

Although his discourse showed that the Agri-Tile machine has potential, it also highlighted the problems discussed above. In order for the Agri-tile machine to be a commercially viable project for Hydraform the tiles that it produces should comply with the relevant SABS standards, which are the only standards available for concrete tiles in South Africa, and should also be consistent with respect to strength and shape. The tile cost must also be kept to a minimum.

4.2 HARISIS

In 1998 George Harisis produced an undergraduate discourse examining the possibility of producing a viable oxy-fluorinated polypropylene reinforced concrete roof tile using the Agri-Tile production system. The use of polypropylene fibres was made possible by the Atomic Energy Corporation of South Africa which found a method of treating polypropylene with a mixture of oxygen and fluorine which allows it to bond with Portland cement.

Harisis found that the addition of the oxy-fluorinated polypropylene fibres not only reduced the strength of the Agri-Tiles but also increased the cost of producing the tiles. Harisis attributed the loss of strength to the fact that:

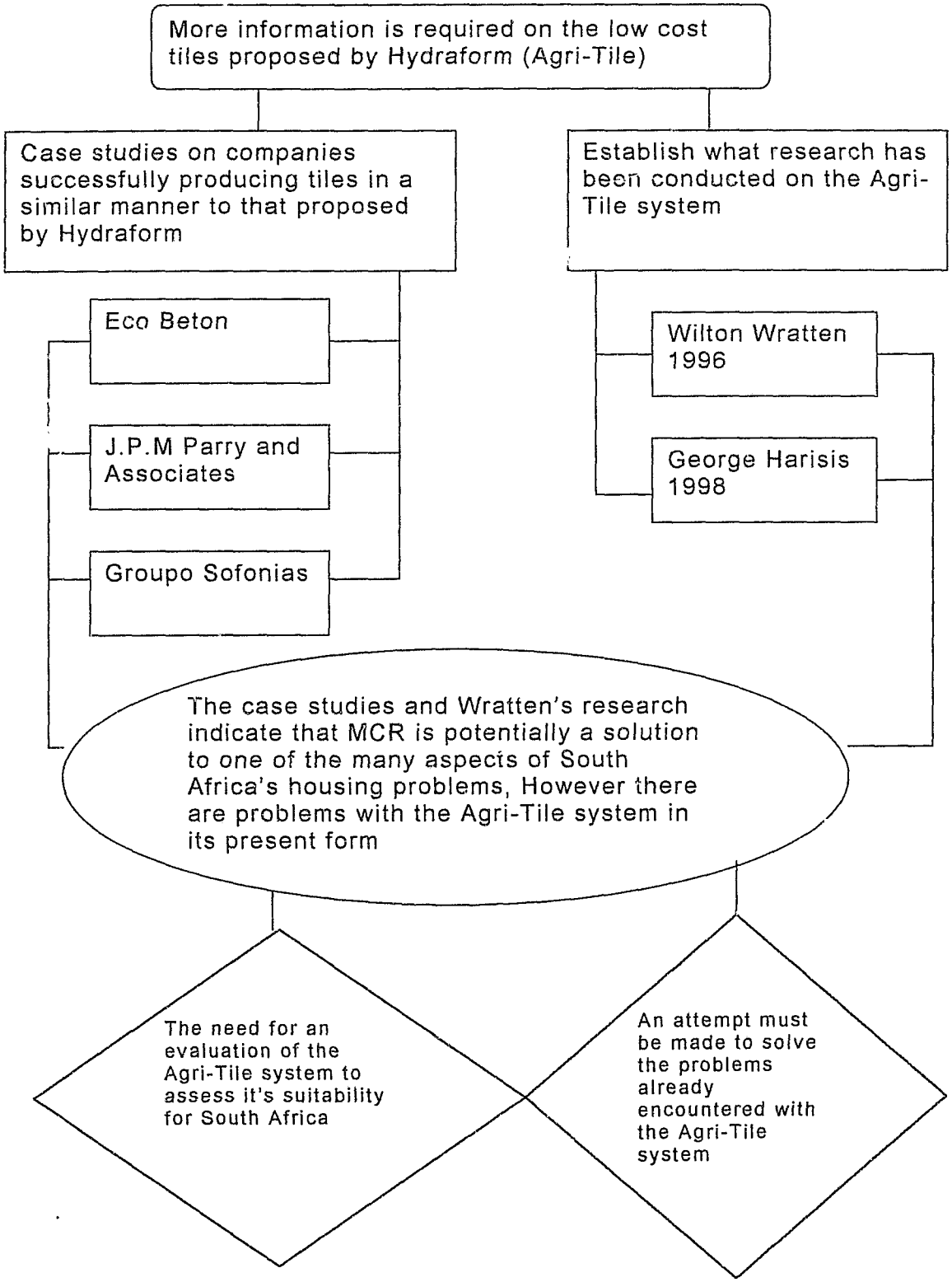
a) The fibres were hydrophilic. This meant that they held water close to them in the initial curing stages, which could introduce small voids at the fibre/mortar interface that could weaken the tile.
b) The mixing process of the mortar "balled" the fibres together, which resulted in high fibre concentrations in certain areas in the tile, leading to a weakness due to the possible lack of cement binding the fibres together.
c) The fibres may not have allowed proper compaction of the tile during vibration, resulting in air voids that would weaken the tile.
d) The tile may have been too thin for the adequate embedding of the fibres.

The findings in this discourse indicate that the addition of oxy-fluorinated polypropylene fibres is not a viable method of improving the strength of the tiles in an attempt to reduce the amount and thus the cost of the cement constituent of the tiles. The results of this research are corroborated by the general trend towards the use of micro concrete instead of fibre reinforced concrete by companies such as Groupo Sofonias and Parry.

CONCLUSION

Laboratory research such as that conducted by Wratten and Harisis is not the only source of information that has be considered. Case studies of three companies producing concrete roof tiles in other countries, using similar technology to that suggested by Hydraform, have also provided a wealth of information. The overall perception created by the case studies and the research conducted by Wratten is that micro concrete tiles can possibly provide a solution to South Africa's roofing problem as they have in other countries. The Agri-Tile system utilises similar technology to that used by the companies investigated in the case studies, yet there is still a lack of technical information available on the Agri-Tile system. Wratten's conclusions indicate that the Agri-Tile system has a number of problems that need to be solved. These problems as well as the lack of technical information indicate that further investigation into this system is warranted and an attempt should be made to refine and improve the Agri-Tile system so that it is capable of meeting the needs of low cost housing development in South Africa.

Flow chart 3: Case studies and earlier research undertaken on Micro Concrete Roof Tiles (MCR) roofing



5. THE AGRI-TILE EVALUATION AND MODIFICATION

5.1 STANDARDS

In order to evaluate a building system there must be an absolute standard against which it can be judged. In South Africa the South African Bureau of Standards has provided a number of requirements that building methods and materials have to meet in order to carry the SABS mark, which indicates that an adequate level of quality is associated with that specific product. However in terms of construction methods and materials the SABS caters for construction methods and materials associated with standard construction practice. Innovative construction methods and materials are referred to the Agrément Board of South Africa which uses a series of tests to determine whether the method or material evaluated is suitable for the purpose for which it is intended.

5.1.1 STANDARDS FOR MECHANICALLY PRODUCED CONCRETE TILES

Mechanically produced concrete tiles have been used successfully in South Africa for over fifty years and their use is an accepted standard method of construction. As such the South African Bureau of Standards has set various standards and criteria against which these tiles can be evaluated.

THE SOUTH AFRICAN BUREAU OF STANDARDS

In South Africa it is not compulsory for concrete roof tiles to comply with SABS specifications although the products of most of the large commercial tile producers not only meet but also exceed these specifications, while the products of many of the smaller tile producers do not meet the SABS specifications. The SABS has two standards for mechanically produced concrete roof tiles, ie, SABS 542 and SABS 062.

SABS 542: A specification for the manufacture & testing of plain and interlocking concrete roof tiles

This specification gives various criteria that must be met when manufacturing plain or interlocking concrete roof tiles to SABS standards. The specification provides the following criteria:

TILE TYPE, SIZE AND DIMENSION:

Specifications are given for the length, width and thickness of the tiles as well as a procedure to be used to determine these dimensions. The specifications for batten lugs, run off channels, nail holes and surface defects are also provided.

TRANSVERSE STRENGTH:

The following test is given to determine the transverse strength of the tiles. The tiles should have an average transverse strength of 4N/mm (Newton's per millimetre of tile width) and an individual transverse strength of at least 3,5N/mm. The test method involves placing the tile on two self-aligning supports 40mm in diameter positioned two thirds of the length of the tile apart. The load should be applied to the tile at a rate not exceeding 6500N/min by a steel bearer 40mm in diameter, midway between the supports, until failure. During testing the longest dimension of the tile should be at 90 degrees to the steel bearers. Tiles should be immersed in water for 24 hours +- 30 minutes before testing. A piece of rubber 13mm thick having an international rubber hardness of 70 degrees should be placed between the steel bearer applying the load and the tile.

RAIN PENETRATION:

To conduct a rain penetration test a rain penetration test rig is required. This test rig has the following characteristics:

- It simulates rainfall on the tiles
- The sides and back of the rig are closed and a relative humidity of 70% is maintained under the tiles during testing
- If the rig is used in the open it needs to be covered to protect it from wind and rain
- Testers should have access to the under side of the roof in the test rig so that observations can be made
- A sparge pipe is placed at the top of the test sample to simulate run off from higher parts of the roof
- A spray or a set of sprays is positioned above the test sample to simulate rain on the tiles. Each tile should get equal amounts of water
- The sparge pipe should provide a simulated rainfall of 150mm/hour
- The spray should provide a simulated rainfall of 75mm/h
- The flow rate for the spray should be calculated using the following equation:

Flow rate (l/min) = 1,25 x actual roof area (in square metres), the sparge pipe should then be given double the flow of the spray.

Test sample: The test sample comprises a section of roof constructed at 30 degrees. Sixteen tiles are placed in a 4x4 arrangement, interlocking tiles having a 75mm headlap and plain tiles having a 65 mm headlap. The sample is subjected to testing for 2 hours after which an inspection of the underside of the tiles should show no free water (in other words no water should have formed on the underside of the tiles or roof structure)

Conclusion

The specifications given for tiles (both plain and interlocking) in SABS 542 are not excessive and will be incorporated in all aspects of this research. Both tests specified (the transverse strength test and the rain penetration test) can be conducted at the university using available and specially constructed equipment. If the specifications given in SABS 542 can be met the tiles produced will be considered similar in quality to the concrete roof tiles produced by large commercial organisations.

The Agri-tile system produces pan tiles. The size of the tile is determined partly by the shape of the moulding frame and partly by the shape of the mould used. As such the SABS 542 specifications for the tile size, shape and dimension found in section 3 points 1 to 7, will not be considered during this research.

SABS 062: A code of practice for the fixing of interlocking concrete roof tiles.

This code of practice applies to the fixing of interlocking concrete roof tiles. It should be noted that no code of practice is available from the SABS for the fixing of plain or pan roof tiles or slate. A substantial portion of SABS 062 is devoted to the sizes of roof structural timber members, their spacing as well as the construction of various roof structural details such as hips, valleys and eaves.

Regardless of the tiles used, SABS 062 states that for different conditions the use of an underlay varies from recommended to essential. This should not change for the design of a new tile as this code of practice states the use of an underlay is recommended at all times.

To determine the required methods of fixing concrete tiles onto roof structures this code of practice evaluates the following criteria:

1) Minimum roof pitch is 17.5 degrees

2) Wind loads calculated on two roof pitches - one of less than 30 degrees and the other greater than 35 degrees

3) Four terrain categories ranging from exposed smooth terrain with no obstructions above 1,5 metres in height to terrain with numerous closely spaced large buildings.

4) The regional basic wind speed

5) The height of the building from the ground to the ridge. Categories range from 3 metre high one storey buildings to 20 metre high 3 storey buildings.

6) Length of the roof slope

The aforementioned criteria are evaluated and used in a number of tables provided to determine which method of fixing is suitable for fixing concrete roof tiles to the particular building in question. Three methods of fixing concrete roof tiles are given and, of the three, method C is to be used in the most severe conditions.

Method C states that roof pitches of between 17,5 and 25 degrees require every tile to be clipped in position, while roof pitches ranging between 25 and 44 degrees require all tiles to be either nailed or clipped in position. For slopes of over 44 degrees every tile must be nailed and clipped, soffits and overhangs must also be closed and an underlay is essential.

CONCLUSION

In certain locations even single storey buildings 3 metres in height require tiles to be fixed in accordance with method C (the most stringent method of fixing) discussed above. This indicates that any tiles evaluated or designed during this research should be designed in such a way that they can be nailed and clipped in position to allow for fixing in accordance with method C.

5.1.2 STANDARDS FOR MANUALLY PRODUCED CONCRETE TILES

The Agrément Board of South Africa

As the manual methods of tile production (such as the Agri-Tile method) are innovative and definitely not standard building practice, the Agrément Board of South Africa (which specialises in determining whether an innovative construction product is fit for the purpose for which it is intended) was consulted. However the Agrément Board of South Africa has no official information available on the testing of roof coverings or roofing systems in general. Although the Board has been involved in the testing of Harveytile and Brown Built's Cliplock these are the only innovative roofing products which have been presented to the Board for evaluation and as such the criteria for these tests were applied to each product on individual merit. No general performance criteria and minimum performance requirements, such as those that are found in the Board's booklets numbered 1 and 2 for walls, are available for roof coverings or roofing systems. This further highlights the need for more research and the development of general performance criteria in this area.

The debate over the meaning of quality and how to apply quality standards in building to the needs and budgets of various income groups comes into play at this point. The only standards that are available for concrete roof tiles are those of the SABS which were designed for mechanically produced concrete tiles, which are middle to high class roof coverings and are generally economically out of reach of the lower income classes. Applying the SABS standards to manually produced concrete tiles could have the following effects:

1. In order to meet the standard the cost of the tile could increase beyond the means of the target market.
2. The manually produced tiles may be deemed unacceptable, even though they may be capable of meeting the needs of the lower income classes.
3. The tiles may be deemed acceptable without incurring any extra cost and as such gain the credibility associated with products that meet these standards.

The National Home Builders' Registration Council (NHBRC) was set up in 1994 to be used for building assessments and applications for bonds. The NHBRC prescribes the building materials and methods that have to be used if clients want to obtain bonds from banks to finance the construction of their houses. There are three ways of obtaining the NHBRC approval for concrete tiles:

1. Design by rules. This means that the relevant SABS specifications must be met.
2. Demonstrate by rational design. The design must be presented to the NHBRC for their approval. The criteria on which this approval is based have not been stipulated.
3. Be in possession of an Agrément certificate.

While the debate over the suitability of the SABS standards for the evaluation of Agri-Tiles continues, these are the only standards which are available for use in the Agri-Tile evaluation and which conform to the requirements of the NHBRC. It was felt that as this is the first comprehensive evaluation of the Agri-Tile system, it should be conducted using standards which are recognised and which will ensure a level of quality that will satisfy the NHBRC.

5.2 THE AGRI-TILE EVALUATION

As can be seen in the proceeding chapters a great deal of research has been conducted on concrete tiles produced using low technology machinery. Together the case studies conducted in chapter 3 and Wratten's discourse, discussed in chapter 4, provide a wealth of information. However combined with the SABS tests conducted on the Agri-tile in 1995 these also highlight the problems associated with this type of tile and tile manufacturing process. Before any attempt can be made to improve on the design of the Agri-tile machine and the manufacture and performance of the Agri-tiles it is essential that an evaluation of the entire Agri-tile system is conducted in order that all aspects relating to its makeup, manufacture and performance become known. Only once this has been completed is one in a position to begin making changes in an attempt to

resolve the problems encountered with this method of tile production. It is also important to remember that the South African economy is a unique blend of the first and third worlds and as such a part solution to the third world housing shortage present will have to satisfy the first world expectations of the South African people.

5.2.1 THE AGRI-TILE SYSTEM

THE AGRI-TILE MACHINE AND ACCESSORIES

The Agri-Tile system comprises the Agri-tile machine, seven moulds and a curing tank. The following descriptions apply to the Agri-Tile machine and accessories in the form supplied by Hydraform and as they were used for this thesis.

1) The vibrating table:
The "Agri-Tile machine" is manufactured from mild steel which is painted to prevent rusting. A base on four legs supports the vibrating table. Each leg can be adjusted in length to facilitate levelling the vibrating table. The vibrating table is a flat piece of sheet metal, which is reinforced by square steel sections welded to it's underside. It is attached to the base by four rubber mountings.

A toothed cog on a shaft (which is fastened to the base) is situated beneath the vibrating table. The cog is attached to a handle and when turned the cog's teeth connect with the edge of a piece of angle iron which is welded across the middle of the vibrating table, this causes the table to vibrate. A bubble type spirit level is attached to the base and is used to level the vibrating table.

An 8mm thick rectangular metal frame is connected to the vibrating table with hinges. This frame determines the shape and thickness of the tile and can be lifted to facilitate the removal of the fresh tile from the vibrating table. The base, to which the legs are attached, is approximately twice the size of the vibrating table in order to provide space for the moulds to be placed next to the vibrating table so that the green tile can be easily transferred from the vibrating table to the mould.

The legs of the machine are detachable and the machine folds in half. The folded machine and all accessories fit into a container which acts as a curing tank while the machine is being used.

2) The curing tank: the curing tank is made from mild steel which is painted to prevent it rusting. The tank is in fact the container in

which the Agri-tile machine and all accessories are stored and transported. The tank has a lid, a lock and handles.

3) The Moulds: Each machine is supplied together with seven fibreglass moulds. The moulds are shaped in an "s" profile characteristic of pan tiles.

PREPARING THE MORTAR

Hydraform recommend a cement to aggregate ratio of between 1:2 and 1:3, and also recommend the use of river sand as an aggregate. Due to the lack of consistency in tile strength and thickness experienced by Wilton Wratten, a cement to aggregate ratio of 1:2 was used for this thesis except for the batches made on 29/1 and 15/4 when a mix of 1:3 was used (as shown in the tile tables – appendix A). Mixing the mortar should be done on a dry clean surface which is free from the residue of previous mixes.

Hydraform state that the water content of the mortar is of the utmost importance as too much water in the mix will cause tiles to be brittle and porous where as too little water produces mortar that is difficult to work and may cause the green tile to crack when it is transferred from the vibrating table to the mould. The water to cement ratio recommended by Hydraform is 1:2. According to Hydraform the water content of the mortar may be checked using the eye-ball test which is conducted by squeezing a ball of it in the hand. If water is forced out, or if water comes to the surface of the green tile during vibration, the mix is said to be too wet. If the ball of mortar is crumbly or if the mortar is difficult to work with then the mix is too dry. Hydraform recommend making a number of trial mixes in an attempt to find the optimal mix for the specific sand being used.

TILE PRODUCTION

The machine and accessories are unpacked and the legs are fitted to the machine. The machine is then levelled, using the spirit level that is permanently attached to the base of the machine, by adjusting the length of the legs until the spirit level indicates that the vibrating table is level. The vibrating table must be kept level at all times otherwise the tiles will not be of uniform thickness. The moulding frame is attached to the vibrating table using sliding hinges and its alignment is checked and straightened if necessary.

Once the machine is set up and the mortar is prepared, Hydraform recommend that the tiles are produced in the following manner:

1. The moulding frame is unhooked, lifted and a suitable plastic sheet is spread over the vibrating table. The moulding frame is then closed and the mortar mix is placed on the plastic sheet. The mortar is spread roughly using a trowel and, while an assistant turns the handle of the vibrating table, the mortar is further spread using the trowel until it forms a flat sheet. Air trapped in the mortar can be seen escaping in the form of air bubbles on the surface of the tile during vibration. Once the bubbling has stopped vibration of the tile can cease. Vibration should last for between 30 and 60 seconds. At this point a fixing hole should be made in the green tile so that the tile can be eventually attached to the roof structure with a nail or wire.

2. The moulding frame is unhooked and, while tapping it gently with the edge of the trowel, it is lifted carefully out of the way. If the frame is lifted without it having being been tapped the green tile sticks to the edges of the frame and breaks. A mould is then positioned on the base next to the vibrating table with the edge of the mould against the vibrating table (they are the same height). The green tile is then transferred onto the mould by pulling the plastic sheet, with the green tile, onto the mould in one smooth movement. The edge of the valley side of the tile is then aligned with the edge of the mould. This must be done accurately or it will result in a deformed tile that cannot be used. The mould with the green tile should be moved to a separate inspection table and examined for proper alignment and damage. A wide wet paintbrush is then used to brush the surface of the tile to remove any irregularities and to increase the humidity at the surface of the tile to prevent shrinkage cracks. This process should take no longer than 5 minutes.

3. The tiles are cured on the mould for 24 hours before they are removed. While the tiles are on the mould a high humidity is needed to prevent shrinkage and drying cracks and to ensure that sufficient moisture remains in the tile to facilitate the hydration process. The tiles are covered with wet hessian and then a plastic sheet to ensure that they are in a sufficiently humid environment.

4. After 24 hours the tiles are uncovered and removed from the moulds. The plastic sheet on which the tiles have been lying is gently removed from the base of the tile. The tiles are then placed upright in a curing tank for a further 7 days. After this period the tiles are removed and inspected for twists, cracks, rough edges or any other defects. The tiles are then ready for use.

5.2.2 LABORATORY PRODUCTION OF TILES USING THE AGRI-TILE SYSTEM

Agri-Tiles were produced using the Agri-Tile method and equipment in the building science laboratory at the University of the Witwatersrand.

MORTAR PREPARATION

The batching process of measuring out the volumes of raw material was used to produce the mortar mix. Volume batching was used for this thesis as it provides a quick, simple and, for this purpose, a sufficiently accurate method of measuring small quantities of material. This method of batching may be unsuitable for site use due to the lack of control of the moisture content of the sand on site. The volume of the sand measured may be the same, but a 5% (by mass) change in the moisture content of the sand can lead to as much as a 40% change in the volume of the sand. A weigh batching system will be more accurate for on site use as a change in the water content of the sand will have far less of an effect on this batching system. The cement to aggregate (river sand) ratio of the mortar used was 1:2, which is the maximum ratio recommended by Hydraform, except for the batches made on 29/1 and 15/4 when a mix of 1:3 was used (as seen in the tile tables – appendix A).

The cement to water ratio of the mortar ranged between 1.5 : 0.5 and 1.5 : 1,8. This ratio was varied in an attempt to ascertain the ratio that provided optimum workability and to ensure that the tiles produced were of the highest standard. Each batch of mortar was mixed in a counter current mixer for 10 minutes.

Three mortar cubes were produced with every batch of mortar used to produce tiles according to the Agri-Tile system. The cubes were kept in their moulds for 24 hours and then placed in the curing tank. This was done in order to check the strength of the mortar and to ensure that tile failure was not due to a defective batch of mortar. The strength of the cubes are shown in appendix A (viii to xiii).

TILE PRODUCTION

The tiles were produced using river sand and in the manner recommended by Hydraform, which is discussed in section 5.2.1 of this chapter. The only deviation from this method was the use of the curing tank in the laboratory instead of the curing tank supplied with the Agri-Tile system. This change was made to due to space and equipment constraints in the laboratory. Detailed descriptions of the tiles produced can be found in the 'detailed tile tables' in appendix A (viii to xxi).

5.2.3 TESTING THE AGRI-TILES

VISUAL INSPECTION

While the SABS 542 specifications for the dimensions of plain and interlocking tiles cannot be applied to pan tiles, the SABS and both Eco-Beton and Groupo Sofonias recommend that each tile be visually inspected for defects.

Visual inspection of the Agri-tiles revealed the following defects:

Rough tiles (rt): Tiles had a rough surface texture which was not aesthetically pleasing. This was influenced by the proportions of the mortar mix.

Rough edges (re): Tiles had rough edges due to mortar seeping below the moulding frame or from the green tile sticking to the moulding frame. This would result in premature failure due to point loading on the uneven edges when the tiles are placed on a roof.

Warped tiles (w): Due to poor alignment of green tiles on the moulds some of them had a warped or twisted shape. These could not be used as the twisted shape would prevent them from overlapping neatly and result in premature failure due to point loading.

Porous tiles (p): Air entrapped in the tiles escaped in the form of bubbles during vibration and in some instances these bubbles left pockmarks on the surfaces of the tiles, which effectively reduced the thickness of the tile at that point thus weakening it.

Hessian sticking to the tile (h): The wet hessian used to cure the tiles often stuck to them, resulting in tiles that were not aesthetically pleasing.

Brush marks (b): Brushing the green tile with a wet soft paint brush increased humidity at the surface of the tile and eradicated some surface defects, but also resulted in brush marks that reduced its aesthetic appeal.

Plastic damage (pd): The Agri-tiles were produced on a plastic sheet which was used to cover the vibrating table. If the plastic sheet had folds or holes in it these imperfections were passed on to the tile. Damage to the tiles ranged from minor blemishes, which only affected the appearance of the tile, to major defects, which reduced its strength.

Uneven tile thickness (l): This does not refer to the variation in tile thickness due to a warped or off-level vibrating table as these defects are difficult to see and must be measured accurately. The uneven thickness mentioned here is caused by a mortar mix which does not flow well on the vibrating table. This causes lumps to form on the surface of the tile which are easily visible. These lumps will prevent the tiles from overlapping neatly, resulting in a leaking roof and will also cause point loading which will result in failure of the tiles.

Cracks (c): Two types of cracks were observed in the tiles. The first type was caused by bending when the tiles were transferred from the vibrating table to the moulds. These cracks were severe and the tile was usually discarded at that point. However, some slight transfer cracks were observed in some of the cured tiles. This second type of crack was caused by rapid moisture loss which caused the tile to shrink and crack. Cracks in tiles reduce their strength and render them unsuitable for use.

The particular defects present in each tile are indicated in the detailed tile tables in appendix A (viii to xxi). The most frequent defects are listed in the average tile tables also found in appendix A (iii to vii). Each defect is marked with one tick if the defect occurred seldom in that batch of tiles, two ticks indicate the defect occurred often and three ticks indicate that the defect occurred almost always. No tick is an indication that the defect was not present in that batch of tiles.

TILE DIMENSIONS

Each tile was weighed and its thickness was measured 30mm in from each corner to avoid irregularities in tile thicknesses which were found to occur at the edges..

TABLE A: SUMMARY OF THE AVERAGE TILE THICKNESSES AND WEIGHTS

		Average tile			
Date produced	Number of tiles	Thickness (mm)	Thickness range (mm)	Weight (kg)	Weight range (kg)
19/1	4	10.0	±0.75	4.588	±0.378
20/1	6	9.9	±1.35	4.882	±0.797
21/1	6	10.1	±1.25	4.968	±0.546
22/1	7	10.1	±1.00	4.861	±0.436
27/1	6	9.2	±0.80	3.986	±0.243
28/1	7	9.1	±0.30	4.168	±0.338
29/1	7	9.0	±0.60	3.861	±0.200
15/4	6	8.4	±0.75	3.837	±0.166
16/4	6	9.3	±0.55	4.311	±0.238
29/6	4	9.4	±0.60	4.051	±0.086
Total	59				
Average		9.4	±0.80	4.290	±0.343

Table A is an extract from tile average table 1. The ideal Agri-tile is 8mm thick while table A indicates that the tiles produced in the laboratory were on average between 8.4 and 10.1mm thick. As can be seen there was a significant variation in the thicknesses of the tiles. Thicknesses varied on average by between ±0.30 and ±1.35mm which represents a variation from the 8mm specification for tile thickness of between ±7.5 and ±33.75%.

The SABS require that the length of the tile to be within ±1.5% or ±1% of the stipulated length, depending on the type and size of the tile. The tile width may not vary by more than ±1.2% or ±0.6% of the stipulated tile width, depending on the type and width of the tile if it is to meet SABS specifications. The SABS has no range of permissible deviation for the thickness of the tile. The only requirement is that the tile is thicker than a minimum figure which cannot be applied to pan tiles of this nature. However it is clear that the variation in the thickness of the Agri-Tiles is well above an acceptable level when compared to the small tolerances in tile length and width stipulated by the SABS.

The SABS has no specification with reference to tile weight. According to Eco-Beton and Groupo Sofonias the weight of the tiles should not vary by more than ±10% of the average tile weight. Table A indicates that of the 10 batches of tiles produced 2 batches had average tile weight ranges of more than ±10%, which is unacceptable.

TILE STRENGTH TEST

The Agri-Tiles were tested in accordance with the transverse strength test set out in SABS 542 and discussed in section 5.1.1 of this chapter. Figure 1 on plate 4 shows the transverse strength test rig used to test the tiles. The tiles tested were 8 days old and were tested within half an hour of being removed from the curing tank. SABS 542 requires an average minimum tile strength of 4 N/mm of tile width and a minimum individual tile strength of 3.5N/mm of tile width.

TABLE B : Average tile strengths

Date produced	Number of tiles	Average tile strength (kN)	Average tile strength (N\mm of tile width of 285mm)
19/1	4	0.71	2.49
20/1	6	0.74	2.60
28/1	7	0.69	2.42
29/1	7	0.56	1.96
15/4	6	0.64	2.25
16/4	6	0.86	3.02
29/6	4	0.65	2.28
Total	40		
Average		0.69	2.43

Table B is a summary of tile average table 1 (appendix A (iii)), and reveals that the tiles did not meet the SABS requirements for tile strength, as the average tile strength was well below the required 4 N/mm of tile width.

RAIN PENETRATION TEST

In order to perform the rain penetration test, set out in SABS 542 and discussed in section 5.1.1 of this chapter, a special rain penetration test rig, which can be seen in figure 2 on plate 4, was constructed at the university. The frame of the rig was manufactured from timber and produced a test roof with a slope of 30 degrees. The battens were spaced at 570mm centres. The runoff from the roof was caught in a gutter, which led the water into a tank. A pump transported the water from the tank to the 6 sprays, which were situated above the test roof. A sparge pipe was used to simulate run-off from higher parts of the roof.

A 3-tap system was used to achieve the required flow rates. The first tap controlled the volume of water supplied to the sprays, the second tap controlled the volume of water supplied to the sparge pipe and the third tap was used to control the volume of water bypassing the system and returning to the tank. A relative humidity of over 70% was observed beneath the test roof at all times during testing. The rain penetration test rig was constructed in manner that complied with all the requirements set out in SABS 542. A detailed description of the rain penetration test rig is given in appendix B (xxii).

The rain penetration test conducted on 3 test samples of 16 tiles each for a period of 2 hours revealed no drops of water had formed on the underneath of the test roof. All of the tiles had however become dark in colour due to water absorption. The Agri-Tiles thus met the requirements of the SABS rain penetration test.

CONCLUSION

The tests carried out on the Agri-Tiles revealed that the rain penetration characteristics of the Agri-tiles met with the required SABS specification. The tile strength was below SABS standard, and the deviations in tile weights and thicknesses were unacceptably high. Of the other defects encountered, the poor alignment of the green tile on the mould (resulting in a warped tile shape) and the cracking of the green tile (when it was transferred from the vibrating table to the mould) were not only the most destructive, but also the most prominent. These two problems will be difficult to prevent.

5.2.4 PROBLEMS ENCOUNTERED WITH THE LABORATORY PRODUCTION OF TILES-USING THE AGRI-TILE SYSTEM

5.2.4.1 THE AGRI-TILE MACHINE AND ACCESSORIES

The vibrating table: The following problems were encountered with the vibrating table:

1. The vibrating table travelled around during vibration. This caused the table to become unlevelled and affected the thickness of the tile. Bolting two of the adjacent legs of the vibrating table to the concrete floor solved this problem.

2. The 8mm steel frame on the vibrating table was warped. This allowed mortar to seep out between the frame and the vibrating table which in turn affected the thickness of the tile. Straightening the frame reduced the problem.

3. The vibrating table does not provide equal vibration to all points of the table. The most vigorous vibration takes place in the centre of the table and this decreases towards the corners. As a result while the corners of the tile still contain entrapped air the mortar in the centre of the table is beginning to separate due to excess vibration. The problem will only be cured by modifying the table.

4. The vibrating table was slightly warped resulting in thickness variations in a tile.

5. The spirit level attached to the base of the vibrating table did not coincide with the level of the vibrating table itself (the spirit level would indicate that the base was level while a spirit level simultaneously placed on the vibrating table showed that this was off level). As a result the vibrating table was levelled with an independent spirit level.

6. The split pin used to hold the handle of the vibrating table in place broke on a number of occasions. This part of the machine will have to be strengthened.

The moulds
The fibre glass moulds supplied were warped and their edges were not straight. As a result all tiles produced on the moulds were also warped.

The curing tank
The curing tank is too small to be used for tile production. When the tiles are transferred to the curing tank from the moulds they are too weak to be stacked on top of one another. As a result only a limited number of tiles will fit into the curing tank. Production will then have to stop to allow these tiles time to cure. Once the first tiles produced have cured for 7 days and are removed from the curing tank they can only be replaced by an equal number of tiles. This will cause a bottle neck at this point in the system and reduce tile production significantly. Either a larger curing tank or an alternative method of curing the tiles will be required if tiles are to be produced on a reasonable scale.

5.2.4.2 THE AGRI-TILE SYSTEM

In addition to the problems encountered with the Agri-tile equipment and accessories listed above, the tile defects discussed in section 5.2.3 of this section indicate a number of fundamental flaws in the actual method used to produce the Agri-Tiles. The problems encountered with this method of the production are:

1. Cracking of the green tile when it is transferred from the vibrating table to the mould

When the plastic sheet on which the green tile is lying is pulled from the vibrating table onto the mould the green tile is forced to follow the contours of the mould. The tile bends first one way, when it goes through the trough of the mould, and then bends the other way when it passes over the ridge of the mould before it comes to rest. The surface of the tile thus experiences compression followed by tension which results in the cracking of the tile. This problem was frequent and resulted in a great deal of wastage.

2. Poor alignment of the green tile on the mould

Great difficulty was experienced aligning the green tile on the mould. This operation was time consuming and errors were frequent due to the lack of any marking or tile alignment

indicators to facilitate the process. This resulted in wasted time and material.

3. The Production and use of concrete moulds

Hydraform supply seven fibreglass moulds together with the vibrating table, which allows the production of seven tiles a day. This translates to roughly a square metre of roof covering a day. In other words it would take 60 days to produce sufficient tiles to cover the roof of a small house with a roof area of $60m^2$. This is too slow and does not utilise capital in an intensive manner. Hydraform state that concrete moulds can be produced in a similar manner to tiles. However the use of concrete moulds means that any fault in the mould will be passed on to all tiles produced on that mould. In Noti-Tejas, The Information Bulletin for the Latin American Micro Concrete Roof Tile (MCR) Network, Katryn Rhyner Pozak states that "It is impossible to guarantee consistent quality tiles if the moulds are not exact. Thus from the outset home made moulds, mainly from concrete, cannot be exact, as differences between one mould and another are the norm and this will not allow for a good final product." The mould is seen as the most important and most expensive item of equipment in the production of MCR tiles [19]. Parry and Groupo Sofonias share similar sentiments and as a result they use only high quality moulds which form the bulk of the cost of their tile producing systems.

While the high quality moulds used by these companies produce a good quality product they are also extremely expensive. All evidence and common sense tells us that the use of home-made concrete moulds will be introducing another variable into an already complicated equation. As such this aspect of the Agri-Tile system is unacceptable. Due to the cost of high quality moulds another solution to this problem must be found.

CONCLUSION

It is clear that in its present form the Agri-Tile system does not produce tiles on a sufficient scale which are of acceptable, uniform quality to be considered a potential solution to the problems encountered in the low cost roofing industry is South Africa. The most significant problems encountered with this system are that the tiles produced have insufficient strength and a high variation in thickness and weight. Problematic tile transfer to and alignment on the moulds, the suggested use of concrete moulds limited production quantities due to the small number of pre-formed moulds supplied, and the small curing tank are all factors inhibiting the efficiency of the system.

First in 1979 Parry and then in 1983 Groupo Sofonias came to the realisation that in order to produce tiles of consistent, high quality special high quality tile production equipment would have to be manufactured and the equipment would have to be operated by trained workmen in a controlled environment. In order for the Agri-Tile system to become a viable roofing alternative in South Africa not only will the problems mentioned above have to be solved, but Hydraform will have to improve the quality of their tile production equipment.

5.3 MODIFICATION OF THE AGRI-TILE SYSTEM

While the engineering modifications that are required to improve the quality of the tile producing equipment, such as the vibrating table and moulding frame, are beyond the scope of this thesis there is a possibility that solutions to a number of the problems encountered can be found.

5.3.1 VARIATIONS IN TILE STRENGTH, WEIGHT AND THICKNESS

The inconsistancies encountered in the tile strengths, thicknesses and weights were due to two factors, one of which was the deficiency in the quality of the equipment used to produce the tiles. The other factor contributing to these inconsistencies was the method of tile production.

Initially an arbitrary amount of mortar was placed on the vibrating table and trowelled evenly over the surface of the vibrating table during vibration, until it was level with the top of the moulding frame. If there was excess mortar it was removed with the trowel, while if the amount of mortar initially placed on the table was too small another arbitrary amount of mortar would be placed on the table to supplement the initial amount.

In order to place the correct amount of mortar on the vibrating table the volume of a tile was calculated and a suitably sized container with graduations was obtained. The container was filled to the required volume with mortar and the mortar was then placed on the vibrating table and trowelled into position.

TABLE C: Average thicknesses and weights of the modified tiles

		Average tile			
Date produced	Number of tiles	Thickness (mm)	Thickness range (mm)	Weight (kg)	Weight range (kg)
30/6	4	8.4	±0.20	3.637	±0.223
1/7	6	8.6	±0.65	4.126	±0.175
7/7	23	8.6	±0.45	4.075	±0.155
9/7	12	8.5	±0.95	4.067	±0.107
Total	45				
Average		8.5	±0.56	4.041	±0.165

Table C is derived from tile average tables 1& 2 (appendix A (iii & iv)). When comparing table C to table A (on page 63) it can be seen that the new method of measuring the volume of the mortar reduced the average tile thickness by 0.9mm to an average of 8.5mm instead of 9.4mm. The average tile weight was reduced by 0.249kg resulting in the initial average tile weight of 4.290kg reducing to 4.041kg. The average range of tile weights reduced from ±0.343kg to ±0.165kg, which means that on average the variation in tile weight was 8.2%. In terms of the standards set by Eco-Beton and Groupo Sofonias this is an acceptable variation.

The new method of measuring the correct mortar volume before placing it on the vibrating table reduced the average range in tile thicknesses from ±0.80mm seen in table A to ±0.56mm seen in table C. This represents an improvement of 6% when related to the specified tile thickness of 8mm. The improved average tile thickness range of ±7% is however excessive when compared to the tolerances in tile length and width permitted by SABS 542.This defect was due to a combination of poor vibration, which failed to cause the mortar to flow adequately and the warped vibrating table and moulding frame which allowed mortar to escape at specific points. This variation in tile thickness will only be further reduced by improving the quality of the tile producing equipment.

5.3.2 THE MOULD ISSUE

A number of the defects encountered in the tiles and the problems encountered when manufacturing the tiles related to the present tile moulding system. An alternative method of shaping the tiles could reduce the tile defects and eliminate the problems encountered with the present moulding system.

The new tile moulding system would have to be cheap, user friendly and be capable of producing a reasonable number of tiles (per batch) of uniform shape. The new system would also have to facilitate tile curing, which takes 24 hours and requires a high humidity.
Initially clay tiles, on which concrete tiles are based, were parabolic in shape and were often moulded on the thighs of the women who made the tiles. As this roofing method evolved and moulds were introduced the tile shape changed to the "S" profile often used today. The parabolic "U" profile is still in use but has lost popularity due to the increased cost and weight associated with this profile due to the larger amount of overlap required to produce a watertight roof, however this profile does have a number of advantages.

The following advantages could be associated with the substitution of the "U" shaped profile for the "S" shaped tile profile currently used by the Agri-Tile system:

1. When the green tile and plastic sheet are pulled onto the mould the surface of the tile will only experience compression as it passes through the trough of the mould before coming to rest. This would significantly reduce the risk of the green tile cracking at this point.
2. The middle of the tile would come to rest in the middle of the trough of the mould. It would be easy to provide tile alignment indicators to facilitate the accurate alignment of the green tile on the mould.
3. The mould would not have to be ridged, as the profile of the tile would be parabolic. Material suspended between two accurately spaced rigid supports would provide the profile shape under the power of gravity. Simply changing the spacing of the two supports could vary the tile profile.
4. As commercial concrete tile manufacturers already produce tiles with a similar profile the "U" shaped Agri-Tile could take advantage of the roof structure and fixing methods already established for tiles with this profile.

It was felt that the potential advantages associated with the proposed parabolic shaped Agri-Tile would provide solutions to a number of the problems and defects associated with the present Agri-Tile, and as such the new parabolic shaped tile warranted further investigation.

DETERMINING THE NEW TILE PROFILE

In order to produce the new tile profiles two rectangular box frames (one of which can be seen in figure 2 on plate 5) were constructed of timber. Each frame had 4 steel bearers, running the length of the frame, on each side. A specifically made piece of drymac material was suspended between the bearers. Drymac is the trade name for a water resistant material which will not deform, shrink or stretch under conditions which frequently vary between wet and dry. The centre line of the material was marked with a line of stitches. Each material mould was large enough to support 2 tiles placed with the short edges facing each other in a head to toe arrangement, allowing each frame to house 8 tiles. The bearers on one side of the frame remained in a fixed position while the bearers on the other side of the frame could be moved between 6 fixed positions creating 6 different tile profiles. The 6 fixed positions were labelled from Aa to E, moving from the widest to narrowest spacing. Figure 1 on plate 7 illustrates these various tile profiles. Table D below lists the width of tile

associated with each bearer spacing when the moulding frame produces a flat green tile of 301mm wide.

TABLE D: Modified tile widths and associated strengths

Date produced	Bearer spacing	Tile width (MM)	Average tile strength (kN)	Average tile strength (N/mm of tile width)
9/7	Aa	275.0	0.918	3.338
	A	265.0	0.998	3.766
7/7	B	252.5	1.184	4.689
	C	245.0	1.236	5.045
	D	235.0	1.412	6.009
	E	222.5	1.440	6.472

These two rectangular box frames were the second attempt at producing a frame to house the material mould. The first frame, which can be seen in figure 1 on plate 5 and in figures 1 and 2 on plate 6, was 3 metres long. The material moulds were continually in the required parabolic position and could not be pulled taut during tile transfer. The result was that the tile would constantly fold in half during tile transfer. An example of this is illustrated in figure 2 on plate 6. The 3 metre long frame was also too large for practical purposes as the frame took a long time to fill with tiles leaving the first tiles placed in the moulds to dry out before being covered. These two problems led to the replacement of the first large frame with the two smaller more versatile frames now in use.

The vibrating table was measured and marked at the mid points of the narrow edges of the tiles. The plastic sheets, which are used to cover the vibrating table, then had V shapes cut into the middles of the narrow edges. When placed on the vibrating table the V cut-outs were aligned with the marks on the vibrating table - this ensured that the v cut-outs in the plastic coincided with the middle of the green tile. When the green tile on the plastic sheet was placed on the material mould the v cut-outs were aligned with the row of stitches marking the middle of the material mould. This ensured accurate tile alignment.

In order to transfer the green tile from the vibrating table to the new material moulds a flat steel sheet with specially placed handles was used. The green tile on the plastic sheet was slipped from the vibrating table onto the steel transfer sheet and moved to the material moulds. Two clamps were constructed to fix to the sides of the frames housing the material moulds and two angle iron bearers were placed across between the two clamps. The steel sheet with the green tile was placed on the iron bearers and the tile was pulled from the steel transfer sheet over on to the material mould. An example of this can be seen in figure 1 on plate 6. At this point the material mould was flat, as the movable

bearer was spaced 400mm from the fixed bearer pulling taut the material of the mould.

Once two tiles had been placed head to toe the movable bearer was moved closer to the fixed bearer effectively lowering the tile into its parabolic profile. This eliminated unnecessary bending of the green tile and reduced the possibility of cracking to a minimum.

Once all four material moulds were occupied by two tiles each, the tiles were sprayed with water using a spray bottle similar to the type used to dispense soaps and window cleaners. This was done to increase humidity at the tile surfaces to ensure that the tiles did not dry out, shrink and crack. The use of the spray bottle was necessitated by the close proximity of the material moulds to one another which made the use of the wet paintbrush difficult. The use of the spray bottle would also avoid the brush marks which defaced the surfaces of many tiles.

The frames housing the material moulds and the green tiles in them were then covered with wet hessian cloth and finally by a plastic sheet. The tiles were left in the moulds for 24 hours before having the plastic sheet removed from underneath them and they were then transferred to a curing tank where they would spend a further 7 days. The relative humidity beneath the wet hessian and plastic sheet covering the material moulds and green tiles for the first 24 hours varied between 95 and 80% over the 24-hour period.

TILE STRENGTH

Table D (on page 72) is a summary of detailed tile tables 6 and 7 (appendix A (xiii to xiv)), and lists the average tile strength in KN and in N/mm of tile width associated with each different tile width. The SABS specification requires tiles to have an average strength of 4 N/mm and an individual strength of 3.5 N/mm of tile width. Table B (page 65) shows that the old Agri-tiles had an average tile strength of 2.43N/mm and thus did not meet SABS specification. Table D (page72) indicates that as material was moved away from the neutral axis of the tile so the tile strength increased. The "B" profile was the first profile to meet the SABS specifications for both average and individual tile strengths. The individual tile strengths can be seen in appendix A (xiii & xiv).
As this profile is the most economical (providing maximum coverage) of the tiles that meet the strength requirements of the SABS it is the profile that will be adopted for the modified Agri-Tiles

VISUAL INSPECTION OF THE MODIFIED AGRI-TILES

As before a visual inspection of the tiles, shown in figure 2 on plate 7, was carried out, this revealed that the following defects were still found in the modified tiles:

Rough tiles (rt): Tiles had a rough surface texture which was not aesthetically pleasing. This was influenced by the proportions of the mortar mix.

Rough edges (re): Tiles had rough edges due to mortar seeping below the moulding frame or from the green tile sticking to the moulding frame. This would result in premature failure due to point loading on the uneven edges when the tiles are placed on a roof.

Uneven tile thickness (l): This does not refer to the variation in tile thickness due to a warped or non-horizontal vibrating table, as this is difficult to see and must be measured accurately. The uneven thickness mentioned here is caused by a mortar mix which does not flow well on the vibrating table and this causes lumps to form on the surface of the tile which are easily visible. These lumps will prevent the tiles overlapping neatly resulting in a leaking roof and point loading which will result in failure of the tiles.

The following new defects were found in the modified tiles:

Drip marks (Dm): The tiles on the upper-most material mould were subject to water dripping from the wet hessian which covered the entire frame. This dripping water damaged the top of the tiles but this defect can be avoided by wringing out the hessian to remove any excess water and ensuring that the hessian is pulled taut over the frame so that any remaining excess water does not collect at the lower sag points and drip from there.

Staining (S): The trough shape of the new tiles combined with the spray bottle method of increasing humidity on the surfaces of the tiles resulted in an accumulation of free water which caused white staining (calcium hydroxide) on their surfaces. This unattractive mark could be wiped off the cured tile.

RAIN PENETRATION TEST

A rain penetration test was conducted on the revised Agri-Tiles. The test was conducted according to the SABS specification and as with the old Agri-Tiles no free water was observed beneath the tiles after the two-hour test period. The tiles thus meet the SABS specification.

CONCLUSION

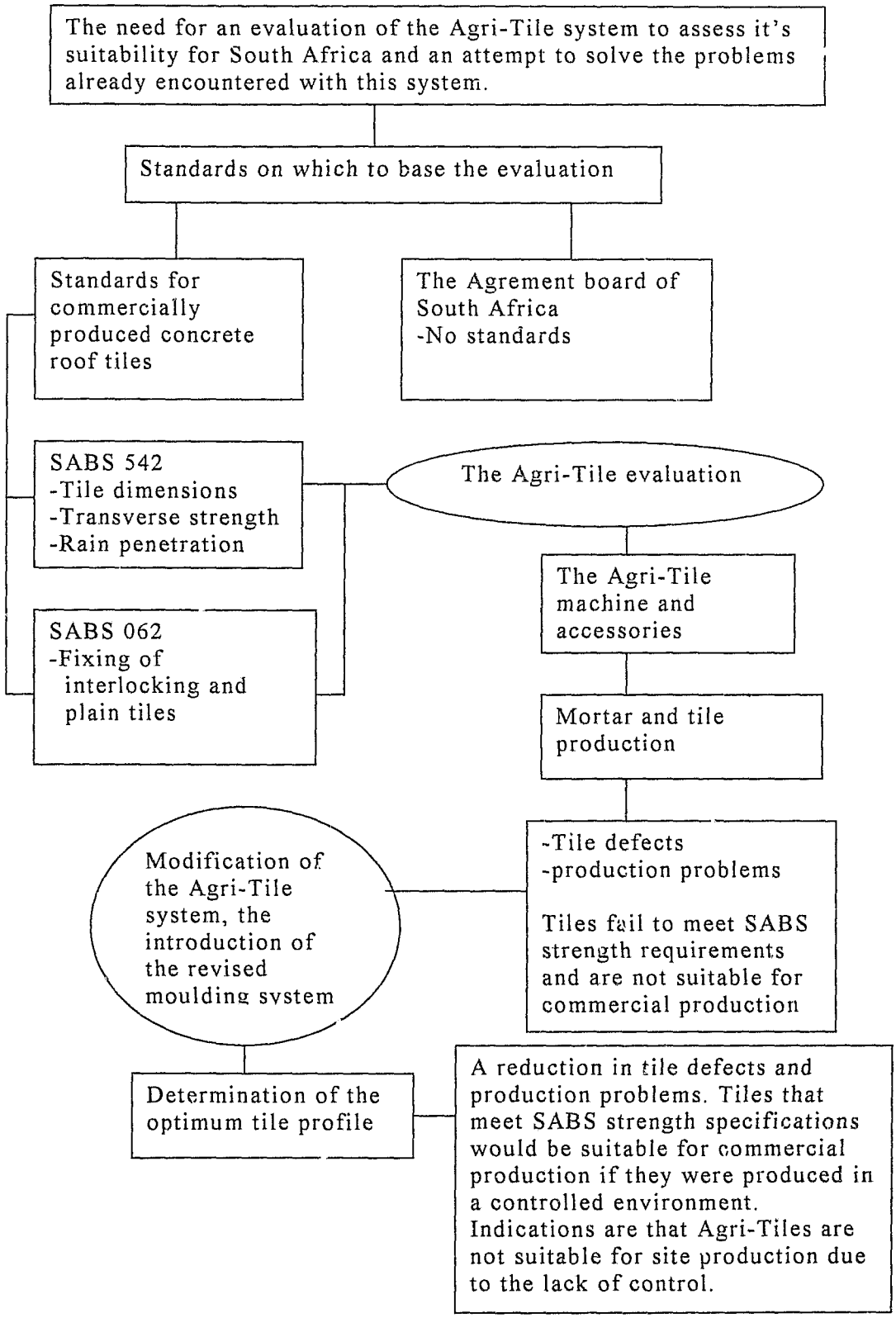
The revised method of dispensing the correct volume of mortar onto the vibrating table reduced the average tile thickness to within 0.5mm of the ideal tile thickness, and reduced the average range of tile weight variation to within the recommended ±10%. The tile strength increased sufficiently to meet the required SABS specification. The modified tiles passed the SABS specified rain penetration test.

The new moulding method eliminated the tile alignment problems experienced with the old moulding system and eliminated the cracking problem experienced when transferring the green tile to the mould. The new defects observed in the tiles are easily prevented and offer no significant problems.

The old defects which recurred in the in the modified tiles are due to the poor quality of the tile producing equipment. The tiles often had a rough appearance and rough uneven edges and the average range of variation in the tile thicknesses was only reduced to ±0.56mm which remains unacceptably high.

Even though the revisions made to the Agri-Tile system have significantly improved it, there remains the issue of the labour skill required to produce these tiles. The tiles are basically hand made and as such the quality of the tiles is dependent on the quality of the workmanship which goes into producing the tiles. In Noti-Tejas May 1997 Katryn Rhyner Pozak states that "visits to 10 MCR workshops in different parts of Honduras confirmed the impression that there are many factors which contribute to good quality tiles. Not all producers work to the same criteria. While some strictly comply with production norms, most fail in some points". Of the numerous small concrete tile producing plants that were prominent at that time and the wide range in tile quality produced, Dobson (1959) states that "The well informed men with whom I spoke were all of the opinion that the only hope for concrete tiles lies in high production of first quality tiles in large factories". History confirmed Dobson's sentiments and the small tile producers went out of business and were replaced with large mechanised factories producing large quantities of good quality tiles.
There is no reason to believe that the experience in Honduras will not be repeated in South Africa, which means that while it is possible to produce good quality MRC tiles the diverse range of people using technology such as the Agri-Tile system would preclude any kind of quality guarantee.

Flow chart 4: The Agri-Tile evaluation



6. MATERIAL EVALUATION

Up to this point the equipment and process used to produce the Agri-Tiles has been under scrutiny, as has the workmanship that goes into producing the tiles. While the quality of the tile is largely dependent on these factors it is also determined to a large extent by the quality of the materials used to produce the tiles which are cement, water and a fine aggregate. All tiles considered in chapter 6 are produced using the improved parabolic profiled Agri-Tiles.

6.1.CEMENT

The word cement can refer to any material which bonds separate materials together. While there are a wide variety of cements used in the construction industry Portland cement is one of the best known and most widely used forms. Portland is not a trade or brand name, it refers to a particular type of constructional cement that is manufactured in a specific way from specific material.

Portland cements are classified as hydraulic cements because they harden when exposed to water and this hardening process involves a chemical reaction between the cement and water referred to as hydration.

Portland cement is produced using limestone and shale that are fired at a high temperature to form a cement clinker. Gypsum is then added to the cooled clinker and they are ground together to form a fine cement powder.

The reasons Portland cement was chosen for this research are because it is used in the construction industry, there is a wealth of information available on it and the fact that it is widely available and relatively cheap.

There are a number of types of Portland cement on the market and each type of cement has different characteristics and uses. The main types of cement are:

ORDINARY PORTLAND CEMENT (OPC)
This is a general all-purpose cement recommended for the vast majority of concretes and mortars. In South Africa between 85 and 90% of all concrete used is OPC.[13]

RAPID HARDENING PORTLAND CEMENT (RHC)
RHC is generally made from the same clinker as OPC, it is however ground more finely than the OPC powder. The finer

powder reacts more quickly with water and gains strength faster than OPC. For similar mixes concrete produced using RHC will at the age of 6 months be stronger than concrete produced using OPC.

SULPHATE RESISTING CEMENT (SRC)
This is a portland cement that has a higher resistance than OPC to attack by sulphates in moderate to high concentrations.

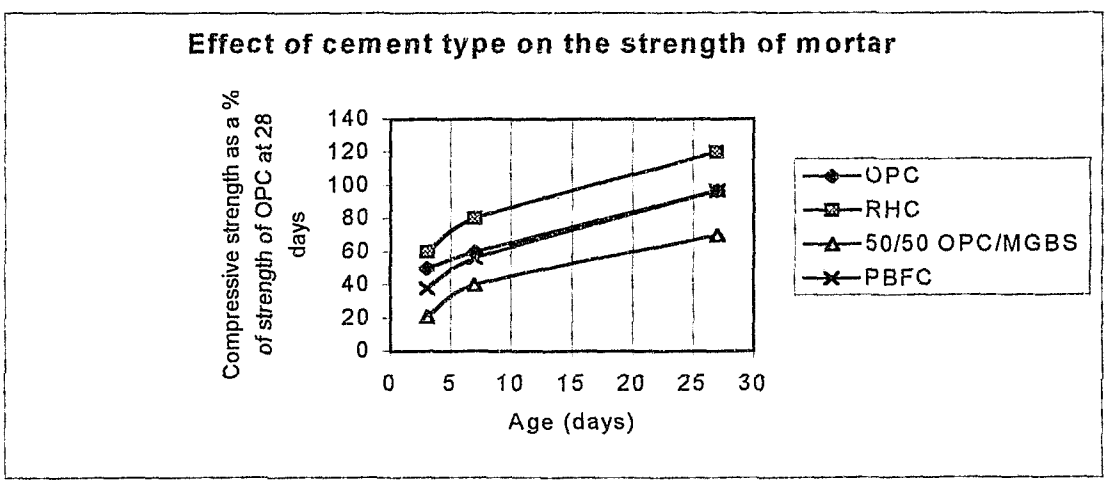
PORTLAND BLASTFURNACE CEMENT (PBFC)
PBFC is a mixture of granulated blast furnace slag and OPC.

PORTLAND CEMENT 15 SL (PC 15 SL)
This is a mixture of OPC and slag. The content of slag may vary between 5 and 15%. Due to the low content of slag PC 15 SL behaves in a similar manner to OPC and as such they can be used for similar applications.

PORTLAND CEMENT 15 FA (PC 15 FA)
5 to 15% fly ash is added to OPC to produce this cement. Once again the low percentage of fly ash in PC 15 SL means that it behaves in a similar manner to OPC and as such they are suitable for similar applications.

RAPID HARDENING PORTLAND CEMENT 15 SL
This is a rapid hardening version of PC 15 SL.

Graph A: (Addis B 1995 Cement concrete and mortar Portland Cement Institute Midrand)



Graph A. shows the compressive strength as a percentage of strength at 28 days for 3 types of cement that all utilise the same water to cement ratio. Analysis of the graph shows that RHC has a 20% greater strength than OPC at 7 days and at 28 days RHC has attained the greatest strength of all the concretes.

According to the manufacturing process of the Agri-Tiles, evaluated in chapter 5, the tiles are removed from the moulds after 24 hours. They are then placed in a curing tank where they are left to cure for a further 7 days. The evaluation revealed that the tiles are weak and susceptible to damage during this early stage. As can be seen in graph.A. the use of RHC will provide the tiles with the extra strength needed to survive this early transfer stage.

The rapid strength gaining properties of RHC make it the most suitable form of portland cement for the production of Agri-Tiles. It is interesting to note that commercial tile producers such as Watson Tile and Marley roofing also use RHC to achieve greater strength quickly in their tiles.

6.2. WATER

According to Fulton's Concrete Technology[13], many authorities have examined the effects of various substances in the mixing water used to produce concrete. While the views expressed have been conflicting, the discrepancies are most likely due to the large variety of methods used to test and cure specimens of concrete.

The effects of harmful substances in the water and aggregate are cumulative and so depend on one another. An aggregate that might be safe to use in conjunction with pure water may be undesirable if used with contaminated mixing water.

In chapter 3 of this thesis Hydraform's intentions with the Agri-Tile concept were discussed and in order for this concept to be a commercial success it was stated that the production of tiles must utilise sand from the building site or surrounding areas. The potentially wide variety of sands that will be available for use makes it very difficult to establish a set of minimum requirements for the mixing water that will be used to produce Agri-tiles.

In 1924 Duff Abrams[13] undertook comprehensive tests to determine the effect of harmful substances in the mixing water on the strength of concrete. Sixty-eight samples of water were tested. The range of samples included sea water, alkaline mine, mineral and bog waters and highly polluted industrial and sewage waste waters. The results of these tests were that in spite of the origin and type of the water used most of the samples gave good results when used as mixing water for concrete. None of the samples tested produced unsound concrete and there were only a few exceptions that caused a delay in the setting of the concrete.

Abrams concluded that neither colour nor odours were indicators to the quality of the water required for concrete production.

G.W Bond (1946) conducted a survey of the underground water supplies in South Africa and concluded that, with a few possible exceptions in the Western Cape and South West Africa, the majority of brackish water supplies can be used with confidence when making concrete.[13]

It can be seen that a wide variety of water is suitable for the production of concrete and it may be assumed that water which is suitable for drinking can generally be used for producing concrete. Exceptions to this include water that is contaminated with sugar and water that has a high sodium or potassium content. [13]

If the only water available is from an untested source the British Standard BS 3148:1980 Tests for water for making concrete recommends that the water source is tested in the following ways:

1. The initial setting time of a concrete test specimen made with the unknown water must not differ from that of a test specimen made with distilled water by more than 30 minutes.
2. The average 28-day strength of concrete test cubes made with the unknown water must not be less than 90% of the strength of the test specimens produced using distilled water.

BS 3148 also points out that the data available regarding the effect of dissolved solids on the strength and durability of concrete is insufficient for a comprehensive system of numerical controls.

The South African Bureau of Standard's SABS 0100 Part 2 1980 suggests that when the quality of water is in doubt "it may be considered suitable for use if the average 28 day strength of three mortar cubes made with the suspect water is a least 90% of that of three mortar cubes made with water of known purity."

The information supplied by Abrams and Bond suggests that almost all water should be suitable for tile production. If water from a particular source is fit for drinking purposes it should be fit for tile production. However where the quality of water is questionable the test suggested by SABS 0100 involving the comparative strengths of two sets of three mortar cubes is simple, cheap and within the scope of most of the potential users of the Agri-Tile machine.

6.3 AGGREGATE

Agri-Tiles are produced using sand as the only aggregate. Fine aggregate sand can be defined as a non-cohesive granular material consisting of particles of sizes mainly between 4.75mm and 0.75mm. Silt refers to particles ranging between 0.75mm and 0.02mm while particles smaller than 0.02mm are clays. The weathering of rocks produces silt, sand and clay.

The criteria to be considered when selecting sand for the production of any form of concrete are the shape, surface texture and grading of the particles. The shape and surface texture of the particles have a significant effect on the water requirement of the mix which in turn impacts on the strength of the concrete. The use of sands that have good characteristics, in other words spherical or cubical shapes, a smooth texture and an acceptable grading profile will contribute significantly to the production of high quality concrete. This concrete will be characterised by low shrink and creep characteristics, a low water requirement and a high strength.

No matter how advantageous the benefits of using a highly suitable sand are, one of the main requirements of the Agri-Tile concept is that the sand used must come from the building site itself or at the very least from the vicinity of the building site. If this requirement is not met the additional cost of transporting sand to the construction site will off-set any economic advantage achieved by using the Agri-Tiles.

6.3.1.HARMFUL SUBSTANCES IN THE AGGREGATE

Many natural aggregates contain substances that are harmful to concrete. There are 4 groups into which harmful substances can be classified:

1. Substances soluble in water, which may be leached out of the aggregate, which will reduce the strength of the concrete or promote efflorescence. An example of such a substance is common salt.
2. Substances that are soluble or may become soluble in the cement matrix which will interfere with the hydration process of cement. Humic acid is an example of such a substance.
3. Sodium sulphate or similar substances which react with the cement and destroy it's properties.
4. Due to the high alkalinity of the cement substances such as opal, which react with the alkaline constituents of the cement, are harmful.

Also while the aggregate itself may be inert it may be coated or encrusted with harmful substances. Mielenz[13] claimed that natural coatings are composed of the following: silt, clay, gypsum, impure carbonates of lime, and magnesia, opaline silica, magnesium oxides, iron oxides, and mixtures of these materials.

Test for the organic content of sand

The test recommended for the organic content of sand uses a 350ml transparent bottle calibrated at the 125 and 200ml levels. The bottle is filled to the 125ml mark with a sample of the sand to be tested. A solution of 3 parts sodium hydroxide to 100 parts water is then added until, after shaking the bottle, the sand and liquid stands at the 200ml mark. The bottle is closed, shaken and left to stand for 24 hours. If the colour of the solution is not darker than that of the light straw standard solution the sand is acceptable.

The standard solution referred to above is obtained by adding 2.5 ml of a 2% tannic acid in 10% alcohol to 97.5ml of the 3% sodium hydroxide solution. The standard mix is shaken and left to stand for 23 hours at which point it is shaken again and left to stand for a further hour. The colour of the standard solution is then used to determine the suitability of the test sand.

This test has problems in that sugar and urine cannot be detected and certain organic substances in the sand which have little or no effect on the strength or durability of concrete produce darker colours than the standard solution.

Test for the fines content of sand

A 250 ml bottle with graduations should be filled with the sand to be tested up to the 100 ml mark. Water is then added until the combined volume of the sand and water is 150 ml. The bottle is shaken vigorously and left to stand for an hour. After an hour the layer of fine material that is observed on top of the sand should be roughly 2.25% or less of the volume (depth) of the sand column in order for the sand to be considered suitable for the production of concrete.

Application of tests to the Agri-Tile process

These 2 tests are simple and can be carried out at the building site by staff with only a little training. However any more complicated tests would be beyond the scope of the average user of the Agri –tile machine.

6.3.2.WATER REQUIREMENT

The water requirement of concrete is the volume of water required per cubic metre of mix to achieve the desired consistency. The water to cement ratio of the mix is influenced by the water requirement of the sand. This has an effect on the strength, impermeability and durability of the hardened concrete as these characteristics are, to a large extent, determined by the water to cement ratio of the mortar mix.

Each site sand used to produce Agri-Tiles will have a different water requirement and as such there is no way of defining a specific water to cement ratio for the mortar mix used to produce the tiles. The water to cement ratio will be determined by the water requirement of the sand used.

6.3.3. GRADING OF THE AGGREGATE

Sands have a great effect on the water demand of concrete. Tests carried out on a large number of South African sands [15] indicate that the void content ranged between 28 to 44%, the average being 36%. This affects the water demand of the concrete significantly. The 16% difference in void content between these sands translates to a difference in water demand of 70 litres per cubic meter of concrete[13]. Voids between the aggregate particles must be filled with cement paste, which increases the cost of the concrete. If the particles are rounded and well graded it is possible to pack them closely and reduce voids and this reduction in voids results in a stronger concrete. The sand grading also has a significant impact on the behaviour of the fresh concrete as well graded aggregates make concrete easy to place and compact [13].

The grading of the aggregate refers to the distribution of particles of various sizes. It is determined by passing a sample of sand through a series of standard sieves. According to SABS 1083 the standard sieve sizes for the grading of fine aggregates are: 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 and 0.075mm.

Each particle size makes a contribution to the properties of the mix. Sand particles larger than 300μm have less effect on the characteristics of the mix than the finer fractions. Their presence increases the body and determines the degree of coarseness of the sand.

The particles that are below 300μm in size play a major role in determining the cohesiveness and workability of the mix. Sands deficient in these particles tend to produce harsh concrete which is prone to segregation. Sands with an excess of these particles will be characterised by a fresh mix that is sticky which can result in handling difficulties. These fine particles can in some instances be responsible for the entrapment of excessive quantities of air and can thus be responsible for a reduction in the strength of the concrete.

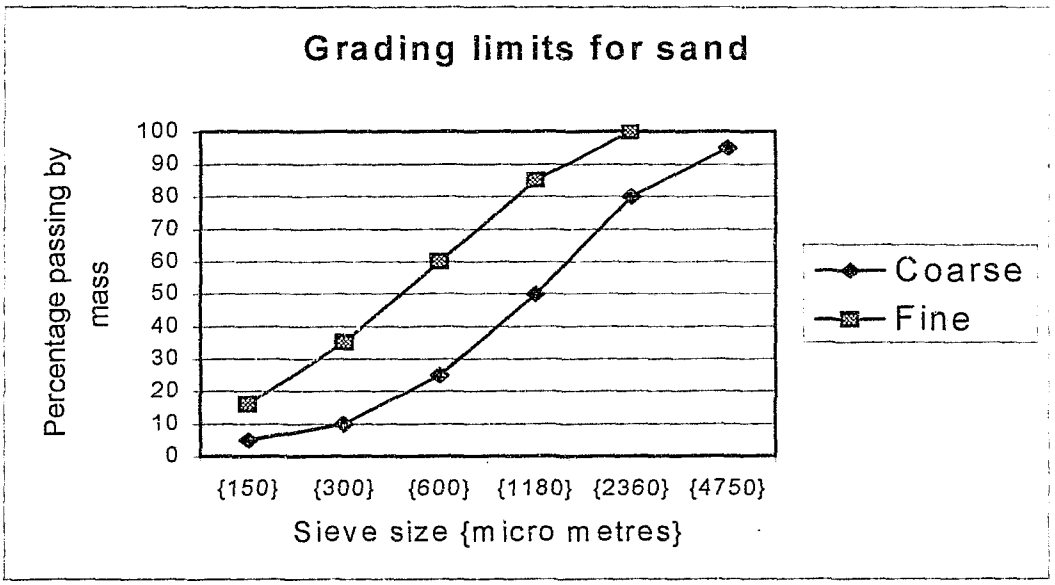
An excess of particles smaller than 75μm may contribute to an increased water demand for the concrete which will result in an increase in the amount of shrinkage that takes place in the hardened concrete. Shrinkage can result in fine cracks that will reduce the strength of the concrete. Particles smaller than 75μm help to control the amount of bleeding that takes place in fresh concrete and hence reduce the harmful effects that this can have on the strength, durability and bond of the concrete.

Table E. (an extract from Addis B 1986) shows the grading envelope for sand suggested by SABS 1083 and the outer grading limits suggested for high quality concrete

Sieve size	Percentage passing		
	SABS 1083	Suggested outer limits	Preferred limits
4750μm	90-100	85-100	90-100
2360μm	-	60-100	75-100
1180μm	-	40-100	60-90
600μm	-	30-75	40-60
300μm	-	15-45	20-40
150μm	0-15	5-20	10-20
75μm	0-5	0-12	3-6

The effect of the grading of the aggregate is not constant on the behaviour of the concrete as this behaviour is also dependent on the cement content and the workability of the cement. The grading analysis does however provide a method of predicting the behaviour of the sand when it is used in concrete[13] and in laboratory investigations it has been found that aggregates with a large deficiency or excess of any size particle are generally undesirable[7]. Despite extensive investigations carried out over many years it has been impossible to determine, from basic principals, an optimum aggregate grading that will ensure suitability for any particular case[13]. However, according to the Portland Cement Institute publication Cement and Concrete, if the grading profile of a sand falls between the limits shown in graph.C (page 87) the sand is usually suitable for use in concrete.

Graph B: Grading limits for sand (supplied by the Portland Cement Institute)



However the grading profile range into which the Portland Cement Institute suggests a fine aggregates grading profile should fall (shown in graph.B) for it to be suitable for the production of concrete does not necessarily apply to the aggregate used to produce micro concrete tiles such as Agri-Tiles. From the case studies conducted in chapter 3 (and table F below) it can be seen that the sand grading profile range recommended by SKAT and used by Groupo Sofonias not only differs from the recommendation of the Portland Cement Institute, but varies according to the thickness of tile produced.

Table F: The sand grading profiles recommended by SKAT for various tile thicknesses

Product thickness	6mm	8mm	10mm
Maximum particle size	4mm	5.5mm	7mm
Component above 2mm	25-45%	30-50%	35-55%
Component between 0.5 and 1.5mm	20-50%	10-55%	10-50%
Component below 0.5mm	15-45%	15-40%	15-40%

In a study conducted by Charles Dobson[17] samples of early concrete tiles of various ages, which were produced in a similar manner to the Agri-Tile were analysed. By modern standards the

tiles used in the study would be regarded as inferior. The aggregate used varied "from coarse pebbly sands to sands of rather uniform, fine grading which would not be regarded today as making for efficient economical production or a good quality tile." The mortar mix used to produce the tiles varied from wet to stiff and dry and the efficiency of mixing was not always good, which resulted in inadequate consolidation of the mix.

Dobson reached the conclusion that "The general good behaviour of the tiles collected was not due to the exceptional care in manufacture or technically high quality."

This study indicates that concrete tiles produced using simple technology such as that used to produce Agri-Tiles can in fact also be produced using a wide range of sands with a diverse range of grading profiles. The water content of the mortar mix can also vary without adversely affecting the quality of the tiles.

There is a discrepancy in the information available on the suitability of sands with different grading profiles which can be used to produce concrete, micro concrete tiles and micro concrete tiles of various thicknesses. The SABS and Portland Cement Institute recommend that the sand used to produce concrete should fall within a fairly limited grading envelope before it is deemed suitable. The case studies of various micro concrete tile manufacturers recommend a wider grading envelope for sand which is used to produce micro concrete tiles, which in the case of SKAT varies according to the thickness of the tiles produced. On the other hand Dobson concludes that a wide variety of sands with a vast range of grading profiles produce tiles that give acceptable performance. This combined with Hydraform's intention of using a variety of site sands to produce Agri-Tiles necessitated a study to establish how sensitive Agri-Tiles are to a change in the grading profile of the sand used to produce them.

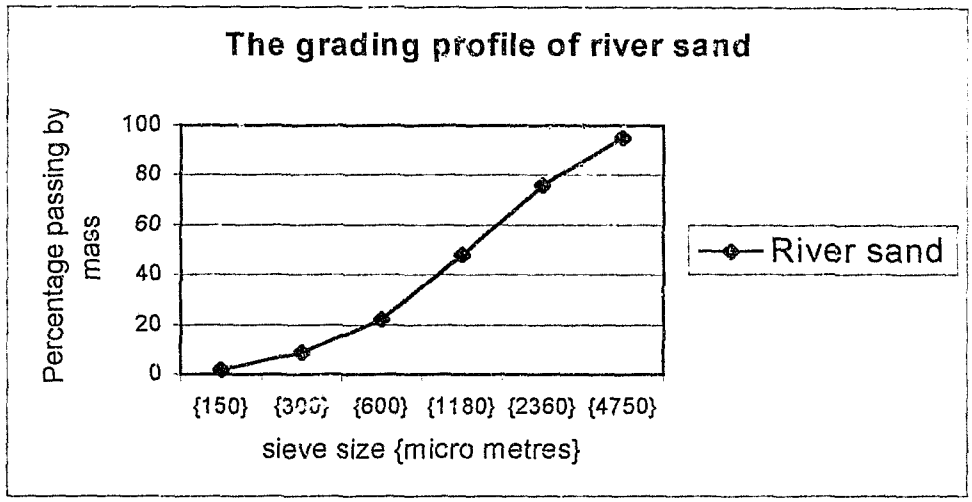
6.3.4.DETERMINING THE GRADING ENVELOPE OF SAND USED TO PRODUCE AGRI-TILES

In order to establish a grading envelope that will enclose all sands with grading profiles that are suitable for the production of Agri-tiles it was decided that a sand which had already been proven acceptable for the production of tiles should be used as a test case. The sand selected for the tests was river sand. This sand was used in the evaluation carried out in chapter 5 of this thesis where tiles that met the SABS strength requirements were produced. River sand is also the sand recommended by Hydraform for the production of Agri-Tiles and Wilton Wratten used it in his 1996 discourse. Wratten showed that the tiles produced using river sand were of an acceptable standard and

that the grading profile of river sand met the requirements of the Portland Cement Institute for sands that are suitable for the production of concrete.

The river sand's natural grading profile was established according to the method in SABS 1083. The sieve analysis of river sand can be seen in graph.C

Graph.C: The natural grading profile of river sand



The natural grading profile of the river sand was then systematically altered in an attempt to establish a grading envelope which encloses all sands suitable for the production of Agri-Tiles. Individually each sand particle size was removed from the natural river sand and then the percentage of the removed particle size was increased gradually in stages. Agri-Tiles were produced at each stage and their strength was then tested in accordance with the requirements of SABS 542.

Other than the restoration of that particular particle size and the water content (as discussed later), all other variables such as the other particle sizes in the natural grading profile, the cement content of the mix and the mixing and manufacturing processes used to produce the Agri-Tiles were held so that any variation in the strength of the tiles could be attributed to the changes in the grading composition of the sand and the water content.

The change in the composition of the natural grading of the river sand also changed some of the characteristics of the sand such as its workability and cohesiveness. This in turn had an impact of the production of the Agri-Tiles as some of the modified grading profiles of the river sand proved exceptionally difficult to work

with. As discussed in chapter 5 Hydraform requires the mortar mix used to produce the Agri-Tiles to be as simple and as cheap as possible, which precludes the use of admixtures to improve the workability of the mix.

Thus the only method available to improve the characteristics of these mixes was to increase the amount of water used when producing the mortar. This in turn changed the cement to water ratio of the mix which had an impact on the strength of the concrete. However in order to produce tiles using river sand with an altered grading profile which is detrimental to the workability of the mix, it was necessary to change the water content of the mix to improve its workability. A change in the strength of the tile made from such a mix could be attributed to the change in the grading profile of the river sand, the increase in water used to produce a workable mix or to a combination of the two. The increase in the water added to the mix was however necessitated by the grading of the sand. As such any change in the strength of the tiles produced, whether due to the altered grading of the sand or to the increase in water content of the mix or both can be attributed directly to, and when producing Agri-Tiles always will be associated with, that particular grading profile of the sand.

6.3.4.1.Changing the grading profile

The percentage that each particle size, ranging from 4750 to 150µm, contributes to the total natural volume of the sand was altered to establish the limits of the grading envelope for sand which is suitable for the production of Agri-Tiles. Particles which were 75µm and smaller (silt and clay) composed only 0.8% of the total percentage of river sand. The test method which was used to establish the amount of silt and clay in the sand is discussed under section 6.3.1 Harmful Substances in the Aggregate as are the maximum allowable percentages of these particle sizes.

Table.G: A summary of the grading changes made to the profile of river sand

Relative graph	Particle size	Percentage of the volume of river sand occupied by the particle size				
6D (pg 90)	4750 µm	0	5	10	15	
6E (pg 91)	2360 µm	0	9	19	29	45
6F (pg 93)	1180 µm	8	18	28	48	68
6G (pg 94)	600 µm	6	16	26	46	66
6H (pg 96)	300 µm	0	13	23	43	63
6I (pg 97)	150 µm	0	7	17	37	57

[Highlighted percentages represent the natural grading of river sand]

Relative average tile strengths for each change to the sand's percentage content of particle size are shown in the tile average tables (appendix A iv to vii). The average tile strength of the "B" profile tiles produced on 7/7 (1.184 kN) was used to plot the values of the percentages highlighted in graph C above as these tiles were produced using natural river sand with an unchanged profile.

Particles retained by the 4750µm sieve

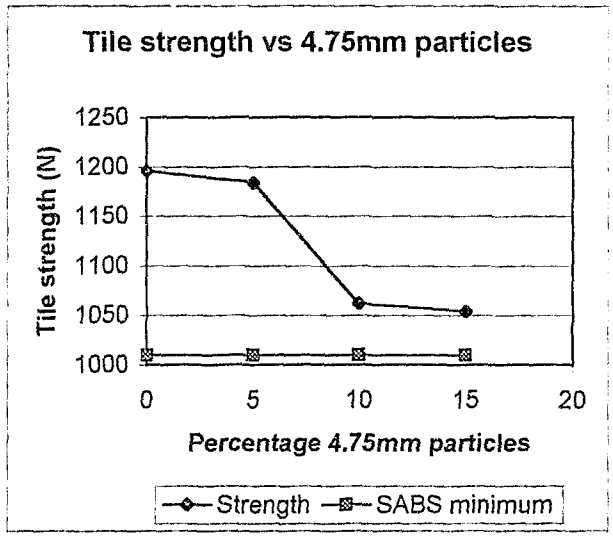
Natural percentage of river sand: Particles retained by the 4750µm sieve constitute 5% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size was completely removed from the sand and then re-introduced in stages of 5%. The sand was used with this particle size comprising 0, 5, 10, and 15% of its volume (see table G above).

Strength tests on tiles:

Graph.D on page 90 shows strengths of tiles produced with river sand containing the specified percentages of particles 4750µm or greater in size.

GRAPH D: Tile strengths relative to concentrations of 4750μm particles in river sand



Examining graph.D reveals that an increase in this particle size leads to a reduction in the strength of the tiles. The loss of strength is relatively low until 5% of the sand consists of 4750μm particles. The majority of the 11.5% loss of tile strength takes place when the percentage of 4750μm particles is increased to between 5 and 10%, after which the strength loss becomes more gradual. When the river sand's volume is composed of 15% 4750μm particles the strength of the tiles is still in excess of the minimum strength recommended by the SABS.

Impact on the characteristics of the mortar:

The increase in the percentage of sand particles of 4750μm and larger present in the volume of river sand used leads to the following changes in the characteristics of the mortar:

- An increase in the coarseness
- A loss of cohesiveness
- When levelling the mortar mix on the vibrating table with a trowel the large particle caused scores on the surface of the fresh tile, which then gradually filled up as the mix was vibrated.

Conclusions:

While river sand with an excess of 15% of its volume composed of particles which are 4750μm or larger can produce tiles of an acceptable strength, these particles reduce the workability and strength of the tile and should be removed from the sand if possible.

Particles retained by the 2360μm sieve

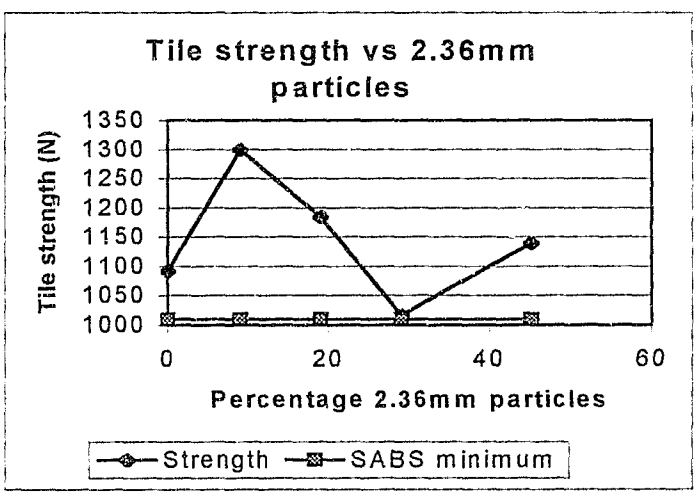
Natural percentage of river sand: Particles retained by the 2360μm sieve constitute 19% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size was completely removed from the sand and then re-introduced to constitute the following volume percentages: 0, 9, 19, 29 and 45%. (see table G page 89)

Strength tests on tiles:

Graph.E. Strengths of tiles produced with river sand containing the specified percentages of particles retained by the 2360μm sieve

GRAPH E: Tile strengths relative to concentrations of 2360μm particles in river sand



From Graph.E it can be seen that when the percentage of 2360μm particles in the river sand ranges between 0 and 45 percent of the volume tiles can be produced which meet the minimum strength requirement of the SABS. The addition of this particle size increases the strength of the tiles until the optimum strength is reached when the 2360μm particles make up 9% of the sand volume. There is a 21.8% reduction in the strength of the tiles, which takes place when the sand is composed of between 9 and 29% of 2360μm particles. A surprising increase in the strength of the tiles takes place when the composition of the sand is made up of between 29 and 45% of particles retained on the 2360μm sieve.

The increase in the strength of the tiles that takes place with the addition of between 0 and 9% of 2360μm particles can be attributed to the optimisation of the grading profile of the sand. Once this optimum profile has been reached the further addition of 2360μm particles degenerates the grading profile resulting in the loss of strength experienced by the tiles when the 2360μm particles comprise between 9 and 29% of the volume of the sand.

The increase in tile strength that takes place when the 2360μm particles make up between 29 and 45% of the volume of the sand can be possibly be attributed to the loss of cohesion experienced by the fresh mix. This enabled the mortar to flow more easily on the vibrating table and thus improved the quality of the workmanship and thus the quality of the tile. Another possibility for this surprising increase in strength could be the reduction in the amount of water required to produce mortar that flows well. The reduction in the amount of water used to produce the mortar increases the cement to water ratio of the mix, which in turn increases the strength of the concrete.

Impact on the characteristics of the mortar:

The addition of sand particles retained by the 2360μm sieve had the following impact on the characteristics of the fresh mortar:

- The coarseness of the mix increased
- Initially an increase in the cohesiveness of the mix was observed. However when the percentage of these particles exceeded 19% of the volume of the sand there was a loss of cohesiveness of the mix.
- A slight reduction in the water requirement of the mix was observed.
- The workability of the mix improved as the cohesivety of the mix decreased

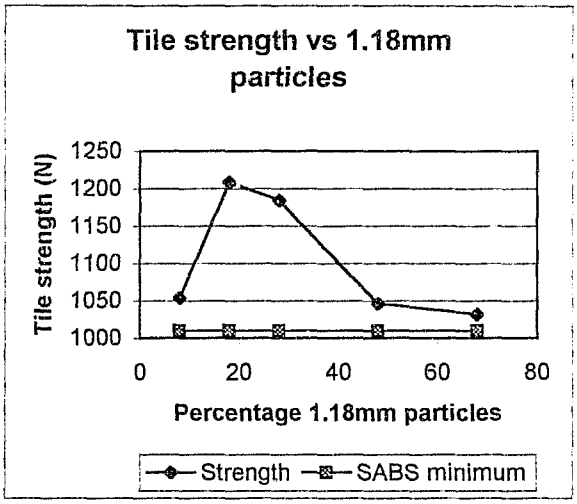
Particles retained by the 1180μm sieve

Natural percentage of river sand: Particles retained by the 1180μm sieve constitute 28% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size is the most prolific size that occurs naturally in river sand. The majority of these particles were removed until those remaining constituted 8% of the volume of the river sand. This particle size was then re-introduced in the following stages: 18, 28, 48, and 68%. (see table G page 89)

Strength tests on tiles:

Graph F: Tile strengths relative to concentrations of 1180μm particles in river sand



The parabolic shape of graph.F shows that the initial addition of 1180μm particles improved the grading profile of the sand, and thus improved the density and compatibility of the mortar. This improved the strength of the tiles. When the sand volume consists of 18% 1180μm particles the sand grading profile is optimum and the further addition of these particles decreases the strength of the tiles. The content of 1180μm particles in the sand tested varied from 8 to 68% of the sand volume and, while percentages above 18% reduced the strength of the tiles, all of the tiles had flexural strengths in excess of the minimum strength required by the SABS.

Impact on the characteristics of the mortar:
The initial deficiency of the 1180μm particles resulted in:

- A cohesive mix which resisted flowing on the vibrating table and was difficult to work with

The increases (from 8 to 48%) in the content of 1180μm particles in the sand resulted in:

- The mortar becoming less cohesive and more workable
- More air bubbles were seen escaping on the surface of the green tile as it was vibrated

When the volume of the river sand consisted of 68% 1180μm particles the mortar became:

- Rough
- Even less cohesive
- Less workable and less inclined to flow on the vibrating table
- Less dense, so entrapped air could be seen escaping in the form of even more air bubbles

Particles retained by the 600μm sieve

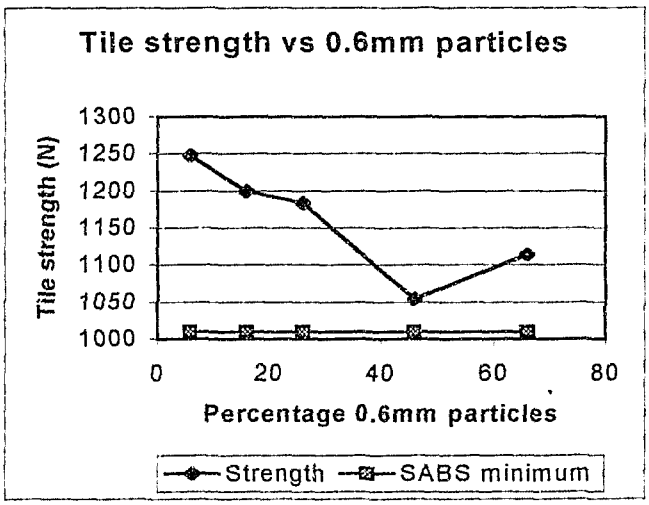
Natural percentage of river sand: Particles retained by the 600μm sieve constitute 26% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size was removed from the sand until the volume of the sand included 6% of 600μm particles. The particles were then re-introduced in the following stages: 16, 26, 46, and 66%. (see table G page 89)

Strength tests on tiles:

Graph.G. Strengths of tiles produced with river sand containing the specified percentages of particles retained by the 600μm sieve

GRAPH G: Tile strengths relative to concentrations of 600μm particles in river sand



From graph.G it can be seen that the tiles achieved the highest recorded strength when only 6% of the volume of the sand was composed of 600μm particles. Any further addition of this particle

size resulted in a decrease in the strength of the tiles. This loss of strength can be attributed to an increase in the water requirement of the mortar, the increase in the amount of air that was trapped in the tile and the decrease in the workability of the mortar. The increase in the strength of the tiles that occurred when the volume of the river sand was made up of between 46 and 66% of the particles retained by the 600µm sieve could not be explained.

Impact on the characteristics of the mortar:

The initial deficiency in the 600µm particle size resulted in:
- A decrease in the water requirement of the mortar
- A high level of workability
- A mortar which flowed well on the vibrating table

Increases in the percentages of 600µm particles in the sand had the following effects on the mortar:
- A proportionate increase of 10% in the water requirement of the mortar
- A decrease in the ability of the mortar to flow on the vibrating table, although the ability of the mortar to flow remained acceptable
- A decrease in the amount of air bubbles escaping during vibration
- A slight decrease in the workability of the mortar although this remained at an acceptable level

Particles retained by the 300µm sieve

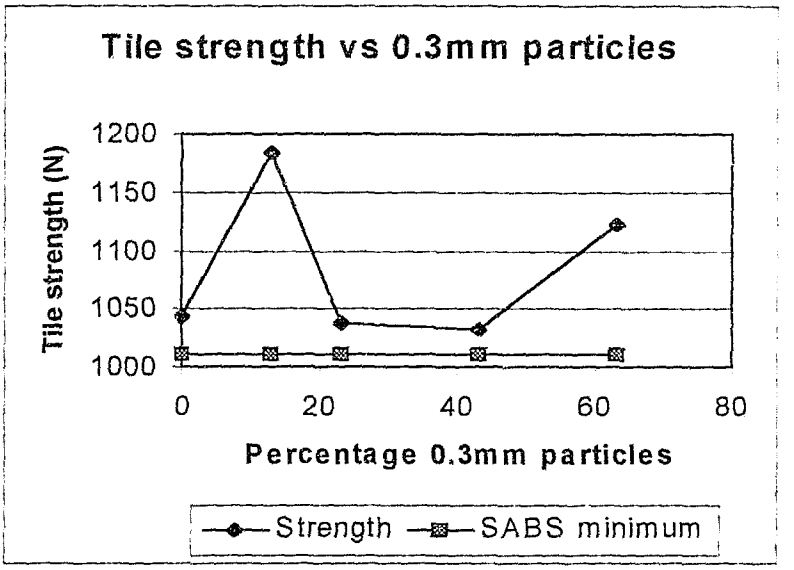
Natural percentage of river sand: Particles retained by the 300µm sieve constitute 13% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size was removed from the sand and then re-introduced in the following stages: 0, 13, 23, 43 and 63%. (see table G page 89)

Strength tests on tiles:

Graph.H. Strengths of tiles produced with river sand containing the specified percentages of particles retained by the 300µm sieve

GRAPH H: Tile strengths relative to concentrations of 300μm particles in river sand



The absence of 300μm particles in the sand resulted in tiles that met the SABS minimum strength requirement by a slender margin. Graph.H shows that the initial increase to 13% 300μm particles produced a significant increase in the strength of the tiles due to the optimisation of the grading profile of the river sand. The further increase in the percentage of 300μm particles moved the grading profile from the optimum and decreased the strength of the tiles produced with the reconstituted sand. A surprising increase in the strength of the tiles occurs when the volume of the sand is composed of more than 43% 300μm particles. This is a similar trend to that found when working with the 2360 and 600μm particles

Impact on the characteristics of the mortar:
The initial absence of 300μm particles in the river sand had the following effects on the characteristics of the fresh mortar:

- The mortar lacked cohesivity
- The workability of the mortar was poor
- Air entrapped in the mortar escaped easily during vibration
- The mortar flowed well on the vibrating table

The addition of 300μm particles to the river sand impacted on the characteristics of the mortar in the following ways:

- The mortar became more cohesive
- The water requirement of the mortar increased by 14% when the volume of the river sand consisted of 43% 300μm particles and by 40% when it increased to 63% 300μm particles
- The air entrapped in the mortar could not escape as easily as it could before the increase in the volume of these particles
- The ability of the mortar to flow on the vibrating table decreased
- The workability of the mortar improved

Particles retained by the 150μm sieve

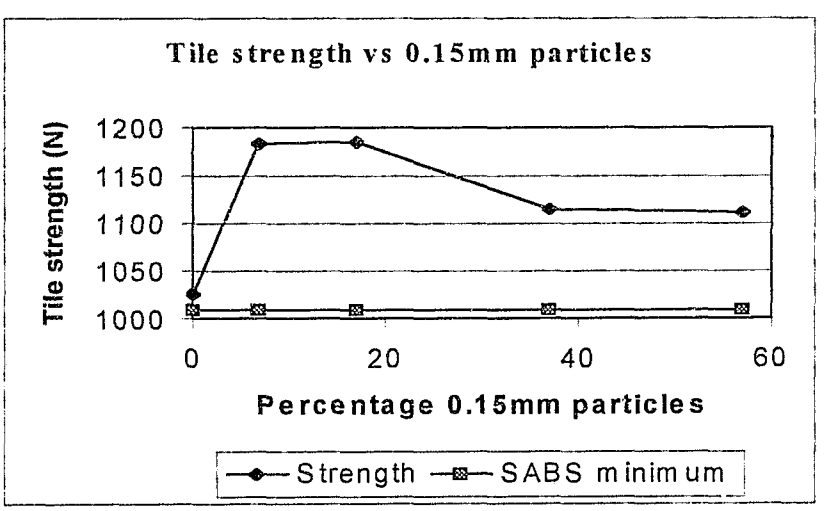
Natural percentage of river sand: Particles retained by the 150μm sieve constitute 7% of the volume of natural river sand.

Changes to the natural grading of river sand: This particle size was removed from the sand and then re-introduced in stages. Tiles were produced from sand with a volume made up of 0, 7, 17, 37 and 57% 150μm particles.(see table G on page 89)

Strength tests on tiles:

Graph.I. Strengths of tiles produced with river sand containing the specified percentages of particles retained by the 150μm sieve

GRAPH I: Tile strengths relative to concentrations of 150μm particles in river sand



As with the 300μm particles the initial increase to 7 percent of 150μm particles had a significant effect on the strength of the tiles. Once the percentage of the 150μm particles was above 7% of the volume of the river sand only a slight increase in the strength of the tiles could be seen in graph.I. The grading profile of the river sand produced maximum tile strength when the *150μm particles composed 17% of the volume of the river sand.* The further addition of these particles reduced the strength of the tiles. The trends seen in the 2360, 600 and 300μm particle sizes, where exceptionally high concentrations of these particles caused a surprising increase in tile strength was not continued with the 150μm particle size. However the increase in the volume of 150μm particles of between 37 and 57% reduced the rate of strength loss of the tiles, with a further loss of only 2 Newtons.

Impact on the characteristics of the mortar:

The absence of the 150μm particles from the sand used to produce the mortar had the following effects on the characteristics of the mortar:

- Texture was rough
- Workability was poor
- Cohesion was poor
- The ability to flow well on the vibrating table increased
- Entrapped air was able to escape easily

The increase from 0 to 37% of 150μm particles in the volume of the sand produced the following results:

- The mortar had a smoother texture
- The workability of the mortar increased
- The cohesive quality of the mortar increased
- The ability of the mortar to flow on the vibrating table decreased
- The amount of air able to escape from the green tile during vibration decreased

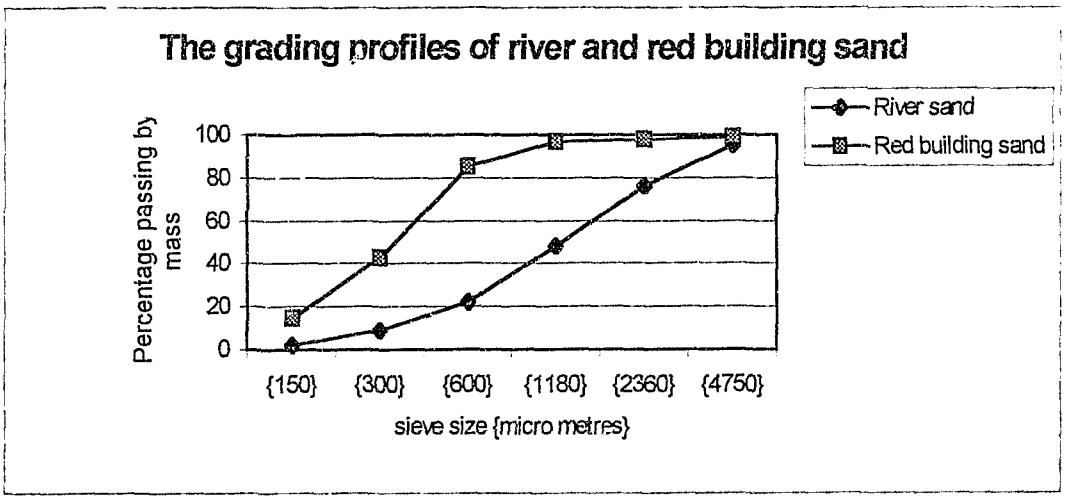
When the 150μm particles constituted 57% of the volume of the river sand, the mortar produced had the following characteristics:

- A smooth creamy texture
- An increase in the cohesive qualities to the point where the mortar became sticky
- Poor workability
- A lack of ability to flow on the vibrating table
- A further reduction in the ability of the air entrapped in the fresh tile to escape during vibration.

HYDRAFORM BUILDING SAND

The strength of the tiles produced using the reconstituted river sand suggests that a wide variety of sands with a diverse range of grading profiles will be suitable for the production of Agri-Tiles. It was felt that to confirm the above conclusion Agri-Tiles should be produced using a sand that previously would not have been considered suitable for their production. The sand selected was red building sand.

Graph J:



Strength tests on tiles:

The tiles produced using red building sand had an average strength of 4.04 N/mm of tile width and the weakest tiles had individual strengths of 3.76 N/mm of tile width and thus met the minimum strength requirements of the SABS.

Characteristics of the mortar produced using red building sand:

As can be seen in graph.J the red building sand is mainly composed of small particles of 600µm and below. With the bulk of the sand volume made up of these small particles the mortar produced using this sand had the following characteristics:

- A smooth creamy texture
- A high degree of cohesivety
- A sticky nature
- Poor workability
- A lack of ability to flow on the vibrating table
- The mortar allowed very little of the air entrapped in the green tile to escape

Conclusions

The tiles produced using red b[illegible]ding sand met the SABS strength requirements by a slender margin. One can thus conclude that a wider range of sand grading profiles will be suitable for the production of Agri-Tiles than previously expected.

CONCLUSION

The initial objective of chapter 6 of this thesis was to determine a suitable grading envelope into which all sands suitable for the production of Agri-Tiles would fit. This was to be accomplished by taking a sand that had previously been identified as suitable for the production of Agri-Tiles, removing each particle size in the grading envelope individually and then increasing, in stages, the percentage that each particle size contributed to the volume of the sand. Tiles were produced at each stage and the effect that the grading profile of the sand had on the strength of the tiles was determined in accordance with SABS standards.

However the research revealed two problems. The first was that the grading profile of the sand should be viewed as a whole and not as a combination of different particle sizes. This is said because the suitability of the sand is determined by the relationships of the volumes of the various particle sizes. In other words, if a sand with a specific content of a certain particle size produces adequate tiles, it does not necessarily follow that sands with different grading profiles but containing the same proportion of that particular particle size will produce similar tiles.

This does not mean that the research conducted was in vain, it simply leads to the second problem encountered. The vast number of different sands and the different grading profiles of these sands means that if the grading profile combination of a sand is to be treated as an individual whole, each case would have to be investigated individually. This would prove to be a monumental task.

The natural grading profile of the test sand was changed significantly. The percentage that each particle size contributed to the total volume of the test sand ranged from a minimum of between 0 and 8% to a maximum of between 15 and 68 percent. All of the tiles produced from these various, wide ranging, grading profiles exceeded the minimum strength requirement of the SABS.

While the research conducted in chapter.6 did not isolate a suitable grading envelope, it did indicate that an exceptionally wide range of sands with diverse grading profiles would be suitable for the production of Agri-Tiles. This agrees with the sentiments expressed by Dobson [17] discussed earlier in this chapter. From this anyone who intends using the Agri-Tile machine to produce tiles on site can be confident that sand available on or near the building site will produce tiles capable of meeting the SABS requirement for strength. This is true as long as the sand conforms to the standards discussed in section.6.3.1 of this chapter, namely Harmful Substances in the Aggregate (page 81).

An important aspect to consider when selecting a sand for tile production is that while it has been established that sands with a wide range of grading profiles can produce acceptably strong tiles the grading profile of the sand influences the characteristics of the mortar and thus the skill needed to produce tiles of an acceptable quality. In order to manufacture tiles with sand producing mortar that flows poorly on the vibrating table or that lacks workability requires a lot more time and skill than producing tiles from mortar made with sands that have more favourable characteristics. As in the evaluation conducted on Agri-Tiles in chapter 5 of this thesis, the level of skill of the person producing the tiles comes into play once again. While the research conducted indicates the wide range in grading profiles of sand that can produce adequate tiles, success will not be possible if the person producing the tiles does not have the necessary time or skill to accommodate sands that produce "difficult mortar."

7. CONCLUSION

In South Africa the rapid population growth, urbanisation and the high rate of unemployment have all contributed towards a high demand for low-cost housing and hence a high demand for relatively cheap, durable construction materials that offer acceptable levels of performance. One of the main problems with existing formal and informal low-cost housing is the predominant use of galvanised steel sheeting which provides the occupants of these structures with a harsh living environment, due to the high level of thermal conductivity which characterises this roof covering.

The survey conducted on the roof coverings available on the South African market revealed that at present no one roof covering is capable of meeting all of the requirements associated with the theoretically ideal low-cost roof covering. Housing shortages and the associated demand for reliable, low-cost construction materials are not an exclusively South African problem. Commercial companies such as Eco-Beton, J.P.M Parry and Groupo Sofonias produce equipment used to manufacture low-cost concrete roof tiles which they claim provides a durable, cheap roof covering capable of meeting the requirements of the low-cost housing markets in the countries in which they operate.

A South African company, Hydraform, is proposing the introduction of MCR to South Africa in the form of their low-cost concrete tile-producing system known as the Agri-Tile system. The evaluation of the Agri-Tile system conducted in this thesis revealed a number of problems which would militate against this system being considered a viable alternative roof covering for the South African market.

Extensive modification of the Agri-Tile system reduced the number and severity of defects present in the Agri-Tiles, the Agri-Tile production system and the tile manufacturing equipment to such an extent that if produced from a variety of sands with a wide range of grading profiles, in a controlled environment, Agri-Tiles can be seen as a possible alternative low-cost roof covering. The quality of Agri-Tiles is however dependent on the quality of the workmanship which goes into producing the tiles and the author felt that when produced in conditions which offer little control the quality and consistency of the tiles produced cannot be guaranteed. It was therefore concluded that in principal the Agri-Tile approach, using the proposed moulding system and a very wide range of sands, could make a contribution to the supply of low cost building materials. However, strict control over quality would be necessary and the author doubts whether this could be achieved consistently over a wide range of building sites.

APPENDIX A

Key to the Tile Average Tables

Table heading	*Interpretation*
Date produced	This is the date on which that particular batch of tiles was produced
Mix (C:S:W)	The proportions of the mortar mix used to produce that batch of tiles (cement : sand : water)
Number of tiles	This column indicates the number of tiles produced in that particular batch. It also indicates the profile of the tiles, a number only indicates the number of original "S" profile produced, while a number followed by a letter indicates the number of parabolic profiled tiles produced and the letter indicates the profile of the tiles.
Tile defects	The most common tile defects are listed. The ticks in the column indicate how often the defect occurred in that batch of tiles √√√-indicates the defect occurred almost always √√-indicates the defect occurred often √-indicates that the defect seldom occurred no tick is an indication that the defect almost never occurred

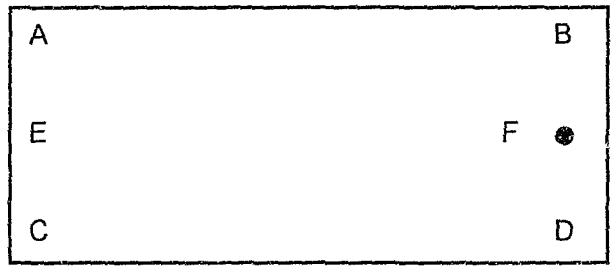
The "B" profile tiles produced on the 7/7 were produced using river sand with a natural grading profile the average tile strength of 1184 kN was used to plot the following values in graphs 6d, 6e, 6f, 6g, 6h and 6i:

5%	4750μm
19%	2360μm
28%	1180μm
26%	600μm
13%	300μm
7%	150μm

Key to the detailed tile tables

Designated areas at which the tile thickness was measured

Tile viewed from above (smooth side facing upward) with nail hole to the right.



Comment on tile defect abbreviation	Tile defect
Rt	Rough tile surface texture
Re	Rough edge
W	Warped tile shape
P	Porous tile (small holes are present)
H	Hessian sticks, leaving marks
B	Brush marks
Pd	Damage due to holes and wrinkles in the plastic sheet on which the tiles are produced
L	Lumpy tile surface
C	Cracks
Bm	Holes due to the formation of bubbles during vibration
S	White stain
F	Folding problem. Tiles with this defect were not tested for strength due to the severity of the defect
D	Marks due to drips falling off the wet hessian

TILE AVERAGE TABLES 1

1998			Average						Production problems		Tile defects						
Date produced	Mix (c:s:w)	Number of tiles	Tile thickness (mm)	Range of tile thickness (mm)	Tile weight (kg)	Range of tile weight (kg)	Tile strength (kN)	Range of tile strength (kN)	Mix workability	Cracks during tile transfer	Rough edges	Porous	Rough tile	Uneven thickness	Irregular shape	Hessian sticking	
19/1	1.5/3/0.6	4	10.0	±0.75	4.588	±0.378	0.71	±0.08	Fair			√√	√√√	√√√	√√√	√	
20/1	1.5/3/0.5	6	9.9	±1.35	4.882	±0.797	0.74	±0.27	Poor	√√	√	√	√√	√√√	√√√	√√	
21/1	1.5/3/0.5	6	10.1	±1.25	4.968	±0.546	----	----	Fair		√√		√√√	√√	√	√	
22/1	1.5/3/0.65	7	10.1	±1.00	4.861	±0.436	----	----	Good	√	√√		√		√	√√√	
27/1	1.5/3/0.75	6	9.2	±0.80	3.986	±0.243	----	----	Good	√	√				√		
28/1	1.5/3/0.85	7	9.1	±0.30	4.168	±0.338	0.69	±0.05	Good		√					√√	
29/1	1/3/0.6	7	9.0	±0.60	3.861	±0.200	0.56	±0.13	Fair						√√	√	
	A defective beam crusher resulted in the delay in tile testing between the 29/1 and the15/4.																
15/4	1/3/0.8	6	8.4	±0.75	3.837	±0.166	0.64	±0.17	Fair	√		√√	√√√			√	
16/4	1.5/3/1	6	9.3	±0.55	4.311	±0.238	0.86	±0.21	Good	√√√		√√√				√√√	
29/6	1.5/3/0.8	4	9.4	±0.60	4.051	±0.086	0.65	±0.07	Fair		√√√		√√√			√√√	
30/6	1/2/0.55	4c	8.4	±0.20	3.637	±0.223	0.84	±0.27	Fair						√		
1/7	1.5/3/0.8	6abc	8.6	±0.65	4.126	±0.175	----	----	Good	Folds	√	√					

TILE AVERAGE TABLES 2

1998			Average						Production problems		Tile defects						
Date produced	Mix (c:s:w)	Number of tiles	Tile thickness (mm)	Range of tile thickness (mm)	Tile weight (kg)	Range of tile weight (kg)	Tile strength (kN)	Range of tile strength (kN)	Mix workability	Cracks during tile transfer	Rough edges	Porous	Rough tile	Uneven thickness	Irregular shape	Hessian sticking	
7/7	4/8/1.35	5B	8.6	±1.25	4.062	±0.198	1.184	±0.14	Fair								
		5C	8.6	±0.20	4.060	±0.165	1.236	±0.13									
		5D	8.6	±0.40	4.104	±0.102	1.412	±0.15									
		5E	8.7	±0.25	4.177	±0.157	1.440	±0.21						√			
		3	8.8	±0.25	3.971	±0.152	0.960	±0.20					√√√	√√√		√√	
9/7	1.5/3/0.8	5Aa	8.4	±0.55	4.030	±0.200	0.918	±0.07	Good		√√						
		5A	8.6	±1.35	3.935	±0.120	0.998	±0.11			√√√						
		2	8.4	±0.00	4.236	±0.002	1.045	±0.02			√√		√			√	
22/7	0.75/1.5/0.45 0% 4750µm	5	9.2	±0.30	4.080	±0 158	1.196	±0.16	Good		√√√	√√√					
	0.75/1.5/0.45 10% 4750µm	5	8.8	±0.20	4.076	±0.289	1.062	±0.31	Poor	√	√√√	√√√					
	0.75/1.5/0.45 15% 4750µm	5	8.9	±0.40	4.090	±0.186	1.054	±0.16	Poor		√	√√√		√√			

TILE AVERAGE TABLES 3

1998			Average						Production problems		Tile defects					
Date produced	Mix (c:s:w)	Number of tiles	Tile thickness (mm)	Range of tile thickness (mm)	Tile weight (kg)	Range of tile weight (kg)	Tile strength (kN)	Range of tile strength (kN)	Mix workability	Cracks during tile transfer	Rough edges	Porous	Rough tile	Uneven thickness	Irregular shape	Hessian sticking
23/7	0.5/1/0.4 0% 2360µm	5	8.8	±0.90	3.915	±0.071	1.092	±0.10	Good		√√√	√√		√		
	0.5/1/0.4 9% 2360µm	5	9.2	±0.20	4.200	±0.072	1.300	±0.14	Good		√	√	√	√√		
	0.5/1/0.35 29% 2360µm	5	9	±0.30	4.121	±0.131	1.018	±0.09	Poor		√√√	√√	√√			
	0.5/1/0.35 45% 2360µm	5	9	±0.25	4.035	±0.107	1.14	±0.15	Poor			√√√	√√√			
27/7	0.5/1/0.4 8% 1180µm	5	9.1	±0.35	4.071	±0.194	1.060	±0.22	Fair		√√	√√√		√√		
	0.5/1/0.4 18% 1180µm	5	9.2	±0.55	4.085	±0.140	1.208	±0.13	Fair		√√√	√√√		√√		
	0.5/1/0.4 48% 1180µm	5	9.1	±0.60	4.127	±0.058	1.046	±0.18	Fair		√√	√√√		√		
	0.5/1/0.5 68% 1180µm	5	9.5	±0.25	4.226	±0.099	1.032	±0.07	Poor		√√	√√	√			

TILE AVERAGE TABLES 4

1998			Average						Production problems		Tile defects						
Date produced	Mix (c:s:w)	Number of tiles	Tile thickness (mm)	Range of tile thickness (mm)	Tile weight (kg)	Range of tile weight (kg)	Tile strength (kN)	Range of tile strength (kN)	Mix workability	Cracks during tile transfer	Rough edges	Porous	Rough tile	Uneven thickness	Irregular shape	Hessian sticking	
29/7	0.5/1/0.35 6% 600µm	5	9.1	±0.50	4.082	±0.203	1.248	±0.17	Good		√√√	√√√					
	0.5/1/0.4 16% 600µm	5	9	±0.65	4.008	±0.098	1.200	±0.15	Good		√√√	√√√	√√				
	0.5/1/0.45 46% 600µm	5	9.1	±0.50	4.007	±0.195	1.054	±0.17	Fair		√√√	√√	√				
	0.5/1/0.6 66% 600µm	5	9	±0.45	4.012	±0.276	1.114	±0.21	Fair		√√	√	√				
4/8	0.5/1/0.35 0% 300µm	5	9.3	±0.80	4.012	±0.131	1.044	±0.12	Poor			√√√	√√√				
	0.5/1/0.4 23% 300µm	5	9.8	±0.35	4.160	±0.231	1.038	±0.08	Good		√√√	√√√	√√√				
	0.5/1/0.4 43% 300µm	5	9.1	±0.15	3.920	±0.087	1.032	±0.18	Fair			√√					
	0.5/1/0.5 63% 300µm	5	9.6	±0.35	4.111	±0.083	1.122	±0.13	Fair		√	√	√				

TILE AVERAGE TABLES 5

1998			Average						Production problems		Tile defects						
Date produced	Mix (c:s:w)	Number of tiles	Tile thickness (mm)	Range of tile thickness (mm)	Tile weight (kg)	Range of tile weight (kg)	Tile strength (kN)	Range of tile strength (kN)	Mix workability	Cracks during tile transfer	Rough edges	Porous	Rough tile	Uneven thickness	Irregular shape	Hessian sticking	
11/8	0.5/1/0.35 0% 150μm	5	9.2	±0.85	4.074	±0.200	1.026	±0.09	Poor	√	√√√	√√	√√√	√√√			
	0.5/1/0.4 17% 150μm	5	9.4	±0.35	4.039	±0.143	1.186	±0.09	Good		√		√				
	0.5/1/0.4 37% 150μm	5	9.6	±0.75	4.101	±0.197	1.114	±0.16	Fair		√√√	√√√					
	0.5/1/0.5 57% 150μm	5	9.2	±0.40	4.010	±0.121	1.112	±0.14	Fair	√	√√√	√√					
7/9	3/6/2 Pit sand	5	10.1	±0.55	4.022	±0.235	1.020	±0.11	Poor		√√√	√√√					

DETAILED TILE TABLES 1

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
19/1	1.5/3/0.6	1	0.78	±1.75	10.6	4.832		11.5	12	10.5	8.5			Rt, w, p,
		2	0.72	±0.50	9.8	4.482	32.8	9	10	10	10			Rt, w, l
		3	0.62	±1.50	9.1	4.141		10.5	9.5	9	7.5			Rt, w, l, h, b
		4	0.70	±0.75	10.4	4.898		10	11.5	10	10			Rt, w, p, l, h, b
20/1	1.5/3/0.5	1	0.81	±1.00	8.8	4.642	37.3	8	10	8.5	8.5			H, p, c, b
		2	1.03	±0.50	11.5	6.030		11	12	11.5	11.5			H, p, c, b, re
		3	0.49	±1.25	9	4.436		8	10.5	9	8.5			H, p, c, b
		4	0.71	±1.00	9.8	4.774		9	11	9	10			Rt, re, c, b, h, p
		5	Sample	±1.25	10.4	4.788		10	12	9.5	10			Pd, h, rt,
		6	0.67	±2.00	10	4.620		12	9.5	8	10.5			Pd, h, rt
21/1	1.5/3/0.5	1	1.33(dry)	±0.75	9.8	4.882	35.4	10.5	9	10	9.5			W, h,
		2	Sample	±1.75	9.3	4.994		7.5	9.5	11	9			Rt, b,
		3	0.81	±1.50	9.5	4.85		8	8.5	10.5	11			Rt, rc, b
		4	1.5(dry)	±0.50	11.8	5.59		11	12	12	12			Rt, rc, b, l
		5	Sample	±1.50	10.3	4.992		10.5	8.5	10.5	11.5			Rt, rc, b, l
		6	Sample	±1.50	10	4.497		8	10	11	11			Rt, rc, b, l

DETAILED TILE TABLES 2

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
22/1	1.5/3/0.65	1		±0.5	9.5	4.398	43.8	9	10	9.5	9.5			H, b
		2		±1	9.1	4.508		8	8.5	10	10			H, b
		3		±1.25	10.5	4.908		9	10	11.5	11.5			H, b, re
		4		±1.75	10.1	5.404		10.5	8	10.5	11.5			H, b, re, pd
		5		±0.75	11.1	5.270		10.5	11	11	12			H, b, re, pd, rt, c
		6		±1.25	10.5	5.054		11.5	9	11	10.5			H, b, rt, pd
		7		±0.75	10.1	4.49		9.5	10	11	10			H, b, rt, pd
27/1	1.5/3/0.75	1		±1.25	9.3	3.87	31	10.5	8	8.5	10			
		2		±1.25	9.1	4.05		10.5	8	9	9			Re
		3		±1.75	9.9	4.206		9	8	11.5	11			W, pd
		4		±1.5	9.9	4.122		9	8.5	11.5	10.5			
		5		±1.5	8.9	3.720		10	7	9	9.5			
		6		±1	8.3	3.950		8	7	9	9			Re, c

DETAILED TILE TABLES 3

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
28/1	1.5/3/0.85	1	0.72	±1	9	4.208	30.2	10	8	10	8			H
		2	0.69	±1.25	9.1	4.216		9	7.5	10	10			
		3	0.68	±1.25	9.4	4.214		9	8.5	9	11			Re, pd
		4	0.68	±0.75	8.9	4.110		9	8	9.5	9			Pd
		5	0.68	±1.5	9.5	4.472		9	8	10	11			H
		6	0.63	±1	9	4.16		9	8	10	9			H
		7	0.72	±1.5	8.9	3.796		9	7	9.5	10			H, re
29/1	1/3/0.6	1	0.54	±0.75	9.6	3.856	30.4	10	8.5	10	10			
		2	0.58	±1.25	8.9	3.852		9	7.5	9	10			W
		3	0.66	±0.75	9.1	3.996		9	8.5	9	10			W
		4	0.4	±0.5	8.4	3.768		8	8	8.5	9			Pd
		5	0.59	±1.75	8.5	3.646		8	7	8.5	10.5			W, h
		6	0.58	±0.75	9.4	3.862		9	8.5	10	10			
		7	Sample	±2.25	9.4	4.046		8.5	7.5	9.5	12			H

DETAILED TILE TABLES 4

1998								Tile thickness at designated points						
Date produced	Mix (c:s:a)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
15/4	1/3/0.8	1	0.63	±1	8.3	3.860	32.6	9	7	9	8			H, rt, pd
		2	0.45	±1.75	7.6	3.660		6	8	9.5	7			H, rt, pd
		3	0.78	±0.75	8.4	3.792		8	8	9.5	8			P, rt
		4	0.55	±0.25	9.1	3.992		9	9	9.5	9			P, rt
		5	0.72	±0.5	8	3.820		8	7.5	8.5	8			Pd, c
		6	0.68	±1	9.1	3.898		9	8	10	9.5			P, rt
16/4	1.5/3/1	1	1.04	±0.5	8.9	4.400	30.1	8.5	9	9.5	8.5			Bm, h
		2	0.63	±1	9.1	4.046		8	9	10	9.5			Bm, h, c
		3	0.95	±0.5	9.6	4.522		9	9.5	10	10			Bm, h, c
		4	0.83	±0.5	8.9	4.306		8.5	9	9.5	8.5			Bm, h, c
		5	0.81	±1.5	10	4.416		9	10	12	9			Bm, h, c
		6	0.90	±0.5	9.3	4.176		9	9	10	9			Bm, h, c
29/6	1.5/3/0.8	1	0.74	±1.25	9.5	4.056	31.5	9.5	8	10.5	10			Rt, h, pd, rc,
		2	0.62	±1	9.8	4.062		11	9.5	9	9.5			Rt, h, pd, rc
		3	0.65	±1	8.6	3.956		9	8.5	7.5	9.5			Rt, h, pd, rc
		4	0.6	±1	9.6	4.128		10	8.5	10.5	9.5			Rt, h, pd, rc

DETAILED TILE TABLES 5

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
30/6	1/2/0.55	C1	0.85	±0.75	8.1	3.338	36.3	7.5	9	8.5	7.5			Pd, w, s
		C2	0.93	±1.25	8.3	3.770		9	9.5	7.5	7			S
		C3	0.51	±0.5	8.5	3.656		9	8.5	8	8.5			S
		C4	1.05	±0.5	8.5	3.784		8	8	9	9			Pd, s
1/7	1.5/3/0.8	A1	Problem	±1	8.5	4.104	32.7	9	7.5	9.5	8			Pd, s, f
		A2		±1.5	8.5	4.024		8	7	10	9			S, f
		B3		±1.5	8.5	4.030		10	7	9	8			P, re, f
		B4		±0.25	8.1	4.374		8	8	8	8.5			F, s
		C5		±2.25	9.4	4.156		9.5	11.5	9.5	7			Re, f
		C6		±3	8.4	4.068		7.5	12	6	8			F,

DETAILED TILE TABLES 6

1998								Tile thickness at designated points						
	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
	4/8/1.35	B1	1.05	±0.5	7.5	3.952	31.9	8	8	7	7			D,
		B2	1.22	±1.25	7.6	4.124		7	6.5	8	9			D,
		B3	1.20	±0.75	10.0	4.154		9	10.5	10.5	10			
		B4	1.13	±0.75	8.3	3.842		9	8.5	8	7.5			
		B5	1.32	±0.75	9.8	4.238		10	9	9.5	10.5			
		C1	1.17	±1	8.5	3.886		10	8	8	8			
		C2	1.39	±0.75	8.6	4.216		8	9	9.5	8			
		C3	1.29	±0.25	8.9	4.068		9	9	9	8.5			
		C4	1.13	±0.5	8.5	4.124		9	8	8	9			
		C5	1.20	±0.5	8.5	4.004		9	9	8	8			
		D1	1.49	±1	8.3	4.232		8.5	7	9	8.5			
		D2	1.39	±0.75	8.1	4.028		9	8	8	7.5			
		D3	1.22	±0.5	8.9	4.122		9	8.5	9.5	8.5			
		D4	1.51	±0.75	8.6	4.056		9.5	8	8	9			
		D5	1.45	±0.75	8.9	4.082		9.5	9	8	9			
		E1	1.63	±0.75	8.6	4.370		9	9.5	8	8			
		E2	1.27	±0.75	8.5	4.208		9.5	8.5	8	8			
		E3	1.22	±0.5	8.9	4.122		9	8.5	9.5	8.5			
		E4	1.51	±0.75	8.6	4.056		9.5	8	8	9			
		E5	1.57	±0.5	9.0	4.130		8.5	9	9.5	9			
		1	0.8	±1.5	9.0	3.800		11	8	8	9			L, rt
		2	1.19	±1	8.8	4.104		9	8	8	10			L, rt,h
		3	0.89	±2	8.5	4.008		10	9	6	9			L, rt,h

DETAILED TILE TABLES 7

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
9/7	1.5/3/0.8	Aa1	0.87	±0.75	8.4	3.848		8	8	9.5	8			Re,
		Aa2	0.88	±0.75	8.4	3.906		8	8	8	9.5			
		Aa3	0.97	±1	8.9	4.248		9.5	8	8	10			Re
		Aa4	1.00	±1	8.4	4.120		7	9	8.5	9			Pd,
		Aa5	0 87	±0.25	7.8	4.030		7.5	8	8	7.5			Re, pd
		A1	1.01	±0.75	8.8	3.802		9	8	8.5	9.5			Re
		A2	1.12	±0.75	8.8	3.950		8	9	9.5	8.5			
		A3	0.9	±2	6.9	3.950		7.5	6	5	9			Re
		A4	0.97	±1.25	8.8	4.042		10	8	7.5	9.5			Re
		A5	0.99	±0.5	9.6	3.930		9	10	10	9.5			Re
		Old1	1.06	±1.25	8.4	4.238		8	8	7.5	10			Re, h.b
		Old2	1.03	±2.75	8.4	4.234		8	6	8	11.5			Rt, re, h

DETAILED TILE TABLES 8

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
22/7	0.75/1.5/0.45 0% 4750µm	1	1.05	±0.75	8.8	3.910		9	9.5	8	8.5	9	9	Re, p
		2	1.19	±0.5	9.4	4.172		9	9.5	9	10	10	9	Re, p
		3	1.36	±1	9	4.226		9	10	8	8	10	9	Re, p
		4	1.13	±1	9.3	3.952		10	10	9	8	10	9	Re, p
		5	1.25	±1.25	9.3	4.138		9.5	10.5	8	9	9.5	9.5	Re, p
	0.75/1.5/0.45 10% 4750µm	1	0.70	±1.5	8.6	4.016		10	7	7	9	9.5	9	Re, c
		2	1.32	±1	9	4.398		9	10	8	8	10	9.5	Re, p,
		3	1.07	±1	8.8	4.158		8	10	8	8.5	8.5	9.5	Re, p, d
		4	1.32	±1	8.9	3.820		7.5	8	9	7	8	9	Re, p, d
		5	0.90	±0.5	8.7	3.986		8	8	9	9	9	9	Re, p, d
	0.75/1.5/0.45 15% 4750µm	1	1.14	±1	8.5	3.930		7.5	8	9	8	9.5	9	P
		2	1.04	±1.25	9.1	4.016		8	7.5	10	10	10	9	P
		3	1.11	±0.5	8.6	4.110		8	9	8	9	9	9	P, l
		4	1.15	±0.5	9.3	4.384		9	9	9	10	10	9	P, l, re
		5	0.83	±2.0	8.8	4.012		9	8	7	10	9	11	P, l

DETAILED TILE TABLES 9

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
23/7	0.5/1/0.4 0% 2360µm	1	1.21	±2.5	9.2	3.868		7	7	8	11	12	10	Re, l.
		2	1.06	±1	8	3.900		7	9	8	8	8	8	Re, p.
		3	1.01	±1.25	8.5	3.886		8	8.5	7.5	8	9	10	
		4	1.11	±1	9.8	4.010		10	9	10	9	10	11	Re, p, l
		5	1.07	±1.5	8.5	3.912		10	7	8	8	8	10	Re, p
	0.5/1/0.4 9% 2360µm	1	1.41	±3.5	9.4	4.264		7	8.5	8.5	9.5	14	9	L
		2	1.14	±1	9.3	4.262		9	8	10	10	9	10	L
		3	1.34	±1.75	9	4.120		8	7.5	9	9.5	9	11	
		4	1.36	±1	9.1	4.212		8.5	8	9	10	9	10	L, p
		5	1.25	±1.5	9.1	4.144		10	10.5	7.5	8	9	10	L
	0.5/1/0.35 29% 2360µm	1	1.11	±1.5	8.9	4.046		9	9.5	8.5	7	9.5	10	Re, rt, p
		2	0.93	±1.5	8.9	4.264		9.5	9	9	7	10	9	Re, rt, p
		3	1.00	±0.75	8.8	4.192		8	8	8.5	8	9.5	9.5	Re, rt, p
		4	1.07	±1	9.4	4.100		8	8.5	8	9.5	9.5	10	Re
		5	0.98	±1	9	4.002		9	10	8	9	9	9	
	0.5/1/0.35 45% 2360µm	1	1.03	±1.25	9	3.982		9.5	9.5	7.5	8	10	9.5	Rt, p
		2	1.04	±1	8.8	3.954		9.5	8	9	7.5	9.5	9.5	Rt, p
		3	1.17	±2	9	4.166		9	9	10	6	10	10	Rt, p
		4	1.33	±1.5	9.3	4.122		9	9	8	11	9.5	9	Rt, p
		5	1.13	±1	9.1	3.952		8.5	9.5	8	9	10	9.5	

DETAILED TILE TABLES 10

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
27/7	0.5/1/0.4 8% 1180µm	1	0.94	±1	8.7	3.958		8.5	9.5	9	7.5	9.5	8	P
		2	0.91	±0.75	9.1	4.222		8.5	8.5	9	10	8.5	10	P, l, re
		3	1.35	±2.25	9.4	4.238		9.5	8.5	9	7.5	12	10	P, l, re
		4	1.12	±0.75	9.4	4.088		8.5	9.5	9	10	9.5	10	P, l
		5	0.98	±1.25	8.8	3.850		7.5	8	8	9.5	10	9.5	P
	0.5/1/0.4 18% 1180	1	1.32	±0.75	8.8	3.942		8.5	8.5	9	8	9	9.5	Re, p, l
		2	1.06	±1.25	9.9	4.222		9	9	11.5	9	10	10	Re, p, l
		3	1.25	±0.25	8.8	4.080		9	9	9	8.5	8.5	9	Re, p
		4	1.23	±1	9.3	4.120		9.5	9	8	9	10	10	Re, p, l
		5	1.18	±1	9	4.062		8	8	9	9.5	9.5	10	Re
	0.5/1/0.4 48% 1180µm	1	0.94	±0.75	9.3	4.146		8.5	9	9.5	10	9.5	9	P
		2	1.27	±1	9.1	4.196		8	9	8	10	9.5	10	P, re.
		3	0.92	±0.5	8.4	4.109		8	8	8	8.5	9	9	P
		4	1.07	±1	9.6	4.080		9	9	11	9	10	9.5	P, re
		5	1.03	±1	9.1	4.102		10	8	8	10	10	9	P, re, l
	0.5/1/0.5 68% 1180µm	1	1.00	±0.50	9.5	4.120		9	9.5	9.5	10	9.5	9.5	P, l
		2	1.13	±1.25	9.5	4.120		8.5	9	9	9.5	11	10	P, l, rl
		3	1.02	±0.75	9.3	4.290		8.5	10	9.5	9	9.5	9.5	Re
		4	0.99	±1	9.8	4.318		10	9.5	10	9	9.5	11	P, l,
		5	1.02	±0.5	9.4	4.282		9	9	10	9.5	9	10	P, l, re

DETAILED TILE TABLES 11

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
29/7	0.5/1/0.35 6% 600µm	1	1.4	±1.25	9.1	4.226		8	8.5	10	8.5	10.5	8.5	P, re
		2	1.11	±1.25	9.6	4.208		9.5	8.5	9.5	9.5	11	9.5	P, re
		3	1.30	±0.75	8.6	3.820		9.5	8	8	8	9	9	P, re
		4	1.07	±1.25	8.9	3.984		8	8	7.5	10	10	10	P
		5	1.36	±1	9.3	4.170		10	9	8	10	9	10	P, re
	0.5/1/0.4 16% 600µm	1	1.15	±1.25	8.5	3.950		8	9.5	9.5	7	9	8	P, re
		2	1.09	±1.25	8.8	4.080		7	9.5	9	8.5	9	9.5	P
		3	1.38	±2.25	8.5	3.906		9	9.5	9	5.5	10	8	P, re, rt
		4	1.25	±1	9.3	4.102		8	8.5	10	10	10	9.5	P, re, rt
		5	1.13	±0.75	9.8	4.002		9	9.5	10.5	10	10	10	P, re, rt
	0.5/1/0.45 46% 600µm	1	0.97	±1.0	8.5	3.938		8.5	8	9.5	10	9.5	10	P, re
		2	0.93	±1	9.3	3.834		8.5	8	9.5	10	9.5	10	P
		3	1.27	±1.25	9	4.224		8.5	8.5	9	8	10.5	9.5	P, re
		4	0.99	±2.0	9	3.934		9	7	8.5	8.5	10	11	P, re
		5	1.11	±0.25	9.5	4.106		9.5	10	9.5	9.5	10	9.5	P
	0.5/1/0.6 66% 600µm	1	1.01	±1	9.4	4.156		9	10	9	8	10	9.5	Re, rt
		2	0.88	±1.5	8.8	3.612		8.5	8.5	10	8.5	10	7	Re
		3	1.30	±1	8.9	4.146		9	10	9	8	10	10	D
		4	1.28	±1.5	8.5	4.164		8	8	8	7	10	10	P
		5	1.10	±1.25	9.3	3.982		9.5	7.5	10	9	10	9.5	P, re

DETAILED TILE TABLES 12

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
4/8	0.5/1/0.35 0% 300µm	1	1.07	±0.5	9.5	4.182		9	10	9	9.5	9.5	10	Rt, p
		2	0.91	±0.75	8.9	3.948		8.5	9	8	9.5	9.5	9	Rt, p
		3	1.15	±1	10.1	3.920		9.5	10.5	11.5	9.5	10	10	Rt, p
		4	1.10	±0.75	9.3	4.088		9	8.5	10	8.5	10	10	Rt, p
		5	0.99	±1.25	8.5	3.924		7	8	8.5	8.5	9.5	9.5	Rt, p
	0.5/1/0.40 23% 300µm	1	1.07	±1.50	9.5	3.920		8.5	10	11	8	10	9.5	Rt, re, p
		2	1.10	±1	10.1	4.300		10	11	9	9.5	10	11	Rt, re, p
		3	0.94	±1.5	10	4.382		9	12	10	9	10	10	Rt, re, p
		4	1.05	±1	10	4.098		10	11	10	9	10	10	Rt, re, p
		5	1.03	±0.5	9.4	4.100		9	10	9	9	9.5	10	Rt, re, p
	0.5/1/0.4 43% 300µm	1	0.83	±1.00	9.1	3.970		8.5	9	10	8	9	10	P
		2	0.99	±0.75	9.1	3.842		9	9	9	8.5	10	9	
		3	1.16	±0.75	9	4.000		8.5	8.5	8.5	9	9	10	P
		4	0.99	±0.25	9.1	3.826		9	9	9	9.5	9.5	9.5	P
		5	1.19	±0.75	9.3	3.964		9.5	9	9	8.5	10	9.5	
	0.5/1/0.5 63% 300µm	1	1.16	±1	9.9	4.214		10	10	9	9.5	11	10	Re,
		2	1.26	±1	9.3	4.106		9	10	8	8.5	10	10	P
		3	1.06	±1.75	9.2	4.064		11	11	10	9.5	11.5	8	Re, rt
		4	1.01	±2	9.7	4.048		9	11	10	7	11	10	
		5	1.12	±0.75	9.8	4.122		9.5	10	10	9	10	10.5	

DETAILED TILE TABLES 13

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
11/8	0.5/1/0.35 0% 150µm	1	0.95	±1.5	8.6	3.924		7	8	9	8.5	10	9	Rt, re, l, c
		2	0.98	±1	9.3	4.016		8	9	9	10	10	10	Rt, re, l, p
		3	1.01	±1.25	9.1	4.122		10	9.5	7.5	8	10	10	Rt, re, l, p
		4	1.12	±1.5	10.3	4.324		9.5	8.5	11.5	11	11	10	Rt, re, l
		5	1.07	±1	9.9	3.982		9	8.5	8	9	9	10	Rt, re, l, p
	0.5/1/0.4 17% 150µm	1	1.07	±1	9.1	3.980		8	10	9	8.5	10	9	Rt, re
		2	1.24	±0.75	9.3	3.842		9	8.5	8.5	10	10	10	
		3	1.18	±1.5	9.6	4.124		8.5	8	10	10	11	10	
		4	1.21	±1.25	9.8	4.128		8.5	10	9.5	9	11	10.5	Re
		5	1.23	±0.75	9.3	4.120		8.5	10	9.5	9.5	9.5	9.5	
	0.5/1/0.4 37% 150µm	1	1.25	±0.75	10.3	4.284		10	11	9.5	10	11	10	Re, p
		2	1.02	±1.5	9.6	4.138		10	10	9	7	10	9.5	Re, p
		3	0.93	±1	9.3	3.960		10	10	8.5	8	9	10	Re,.p
		4	1.17	±0.75	8.8	3.890		8	9.5	9	8.5	8.5	9	B
		5	1.20	±1.25	9.8	4.232		9	9	11.5	9.5	10	10	Re, p
	0.5/1/0.5 57% 150µm	1	0.95	±0.75	8.9	3.940		9.5	8	9	8.5	9.5	9	Re, p, s
		2	1.16	±0.5	9.5	4.182		9.5	9	10	9	9.5	10	Re, p
		3	1.23	±1.5	9.3	3.950		8	9	9.5	8.5	10	11	Re, p, c
		4	1.03	±0.5	8.7	3.952		8	8	9	9	9	9	Re, p
		5	1.19	±1.25	9.4	4.026		8	9	10.5	9.5	10.5	9	Re

DETAILED TILE TABLES 14

1998								Tile thickness at designated points						
Date produced	Mix (c:s:w)	Tile number	Tile strength (KN)	Tile thickness range (mm)	Average tile thickness (mm)	Tile weight (kg)	Mortar strength MPa	A	B	C	D	E	F	Comments on tile defects
7/9	3/6/2 Pit sand	1	0.95	±1.75	10.3	4.120		11	9	11	8	11.5	11.5	Re, p, s
		2	1.03	±0.75	10.7	4.184		10	10	10	11	11.5	11.5	Re, p, s
		3	1.17	±1.25	10.1	4.234		9.5	10.5	9	10	11.5	10	Re, p, s
		4	0.95	±0.5	9.6	3.764		9	9	10	9.5	10	10	Re, p
		5	1.00	±0.75	9.6	3.808		9	9.5	10.5	9	10.5	9	Re, p

APPENDIX B

THE RAIN PENETRATION TEST RIG

Illustrations of the rain penetration test rig can be seen in figure 2 on plate 4 and in figures 1 and 2 on plate 8.

This test rig was used in the laboratory at the university at all times and was protected from wind and rain during testing.

The frame

The frame of the rain penetration test rig was constructed out of timber. The frame measured 3 metres long, 2 metres wide and 1.5 metres high. The timber members were held together using screws and gang nail plates.

The timber sections were as follows:

- The 4 timber uprights and the 2 timber sections inclined at 30 degrees, forming the trusses for the test roof, were 38x100mm sections
- The remaining timber sections were all 38x38mm sections
- The purlins were 38x38mm sections and were spaced at 570mm centre to centre.

A door was supplied at the back of the rig to provide testers with access to the under side of the test roof to make observations during testing. Hinges at the top and bottom of the right hand side of door attached it to the main frame and two fastening devices on the top and bottom of the left hand side kept it closed during testing.

The sides and front of the frame as well as the door at the back of the frame were covered with PVC sheeting, which was stapled to the wooden frame to ensure that a humidity of 70% and above could be maintained beneath the test roof during testing. A clear plastic window was placed in the door so that a hygrometer placed in the frame beneath the test roof could be observed during testing. The hygrometer was used to monitor the relative humidity below the test roof during testing.

A 2 metre long section of gutter that was closed at one end and had an outflow pipe at the other was fixed to the front purlin and positioned in such a way that it would catch all the runoff from the test roof.

A timber frame in the shape of an "I", which was 3 metres long, was suspended 400mm above the test roof.

The sprays and sparge pipe

The sparge pipe was manufactured by using a 2 metre long section of 20mm irrigation pipe that was closed a one end. A series of holes were made on one side, along the length of the pipe, from which water could escape. Water was supplied to the sparge pipe via the open end.

6 Irrigation sprays were mounted on the "I" shaped timber frame suspended 400mm above the test roof. The sprays were distributed along the length of the "I" shaped timber frame so that all the tiles in the test roof below the sprays received an equal amount of water. The 6 spray heads were supplied with water via 3 pipes. One pipe fed 2 spray heads, this was done to reduce the loss of water pressure due to friction in the narrow pipes.

A tank served as a water reserve. The gutter, which collected the water runoff from the roof, returned it to the tank to avoid wastage.

A Speck pump supplied water from the tank to the sprays and the sparge pipe via a three tap system, the taps being connected in parallel. The first tap regulated the amount of water flowing to the sprays, the second tap regulated the amount of water flowing to the sparge pipe and the third tap controlled the pressure in the system by regulating the amount of water bypassing the system and returning it to the tank.

The flow rates required for the test rig were calculated in the following way:

- Each tile provided 530mm x 240mm of coverage which equalled 0.1272 m^2
- The test roof was made up of 16 tiles in a 4 x 4 arrangement. This gave a test area of 2.0352 m^2
- The flow rate for the sprays was calculated using the following formula:
  Flow rate (litres per minute)= 1.25 x actual roof area in m^2
  = 1.25 x 2.0352m^2
  = 2.544 l/m
- The flow rate for the sparge pipe was double that of the sprays, which equalled 5.088 litres per minute

In order for the test rig to supply the flow rates calculated above it had to be calibrated. Only the water landing on the test roof, which the gutter collected was used to calculate the flow rates of the test rig. The water supplied by both the sprays and sparge pipe that missed the test roof was ignored.

The test rig was calibrated in the following manner:

1) With the pump running the bypass tap was opened half way.
2) The tap supplying water to the sprays was then opened .
3) The volume of water collected by the gutter, which represented the volume of water landing on the test roof was caught for a period of one minute and measured. The tap was then adjusted until the required flow rate of 2.544 l/m was achieved.
4) The position of the tap supplying the sprays with water was then marked.
5) The tap supplying the sprays was then closed, the bypass tap remained half open and the tap controlling the water flow to the sparge pipe was opened
6) The volume of water collected by the gutter, which represented the volume of water landing on the test roof was caught for a period of one minute and measured. The tap was then adjusted until the required flow rate of 5.088 l/m was achieved.
7) The position of the tap supplying the sparge pipe with water was then marked.
8) Both the tap that supplied the sprays and the tap that supplied the sparge pipe were then opened to the marked positions. The bypass tap remained half open.
9) The combined volume of water supplied to the test roof was then caught for a period of one minute. The combined flow rate of the sprays and the sparge pipe equalled 7.632l/m which was the required combined flow rate. The slight drop in pressure resulting from simultaneously opening the tap that supplied the sprays and the tap that supplied the sparge pipe did not affect the flow rate of either the sprays or the sparge pipe.

PLATE 1



Figure 1: Tile Original Agri-Tile

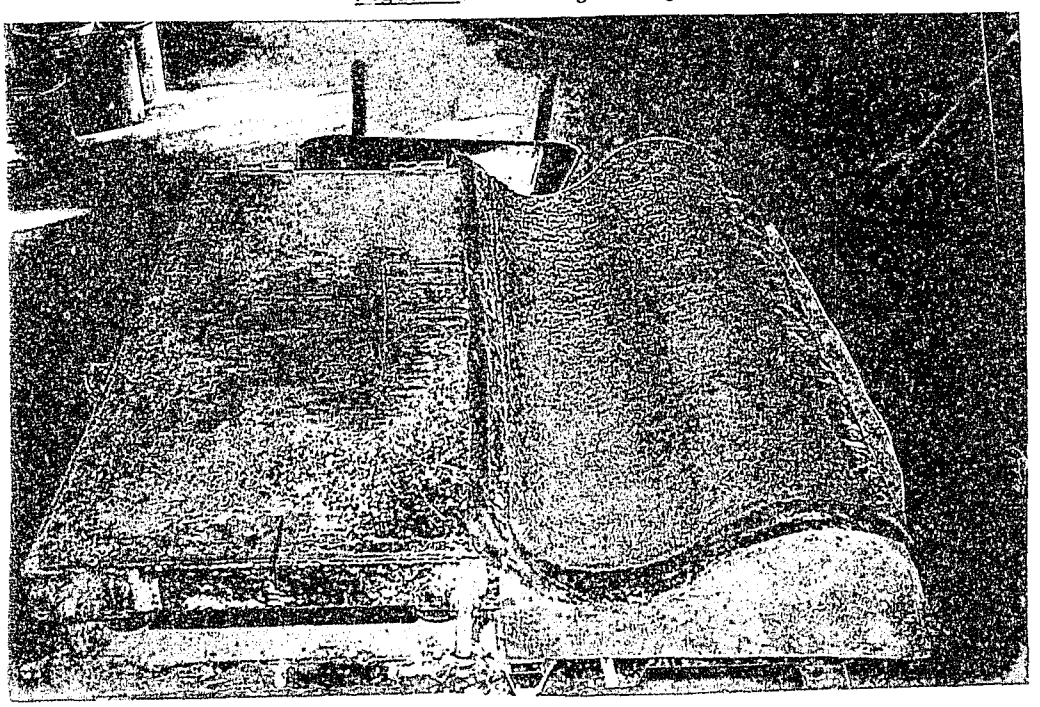


Figure 2: Moulding the original Agri-Tile

PLATE 2

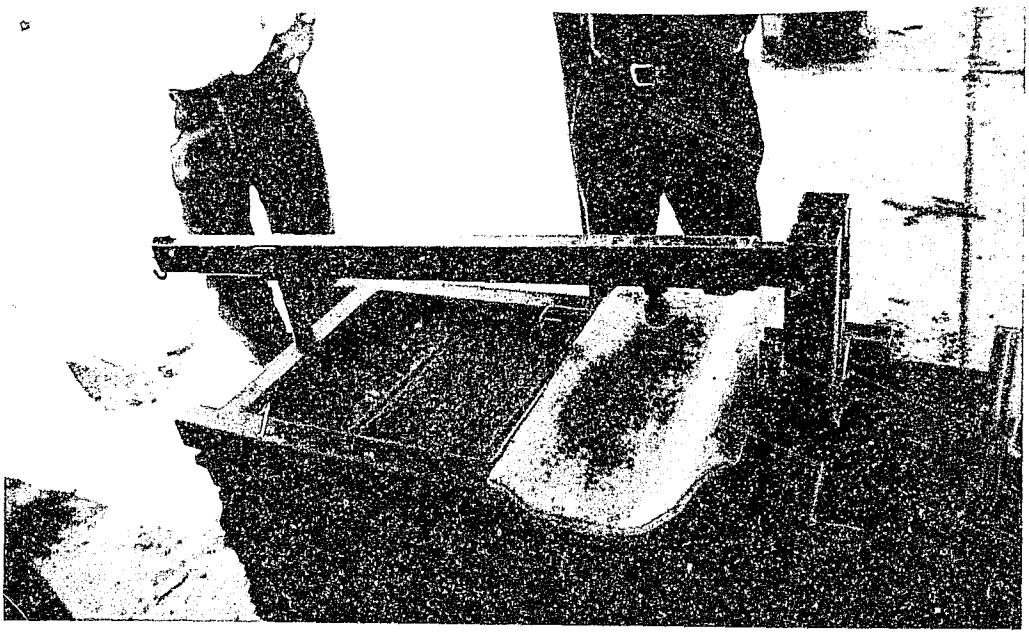


Figure 1: The apparatus used to test the transverse strength of tiles produced by Groupo Sofonias. Unfortunately the third bearer was not available at the time of taking the photo.

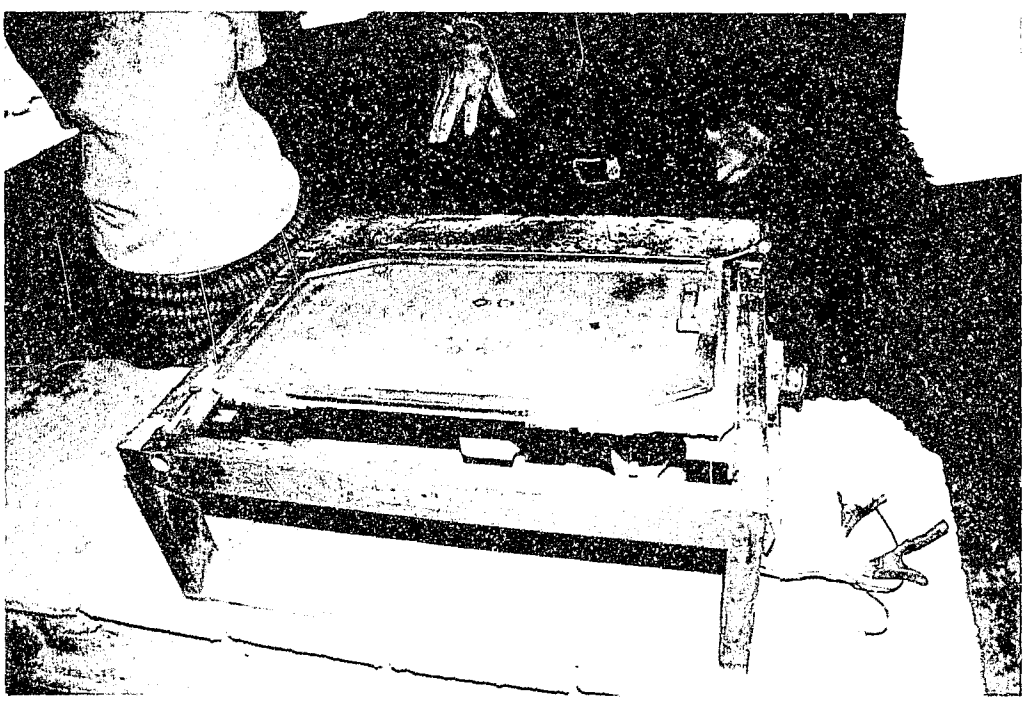


Figure 2: The vibrating table used by Groupo Sofonias (note the mitres on the diagonally opposite corners and the box mould used to form the nib on the tile)

PLATE 3

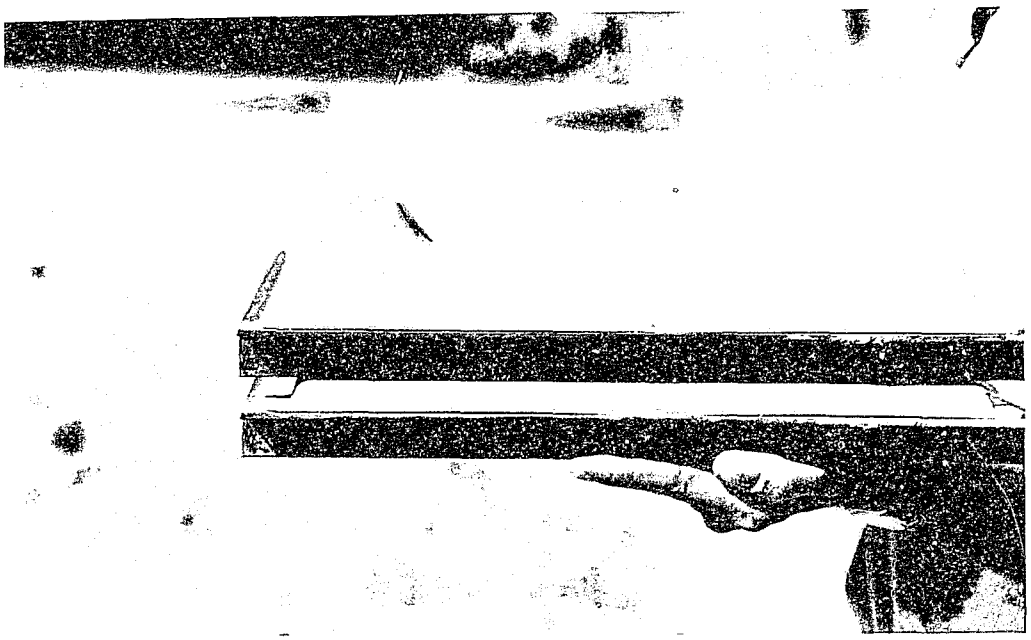


Figure 1: Examples of the high quality injection moulded polypropylene moulds used by Groupo Sofonias

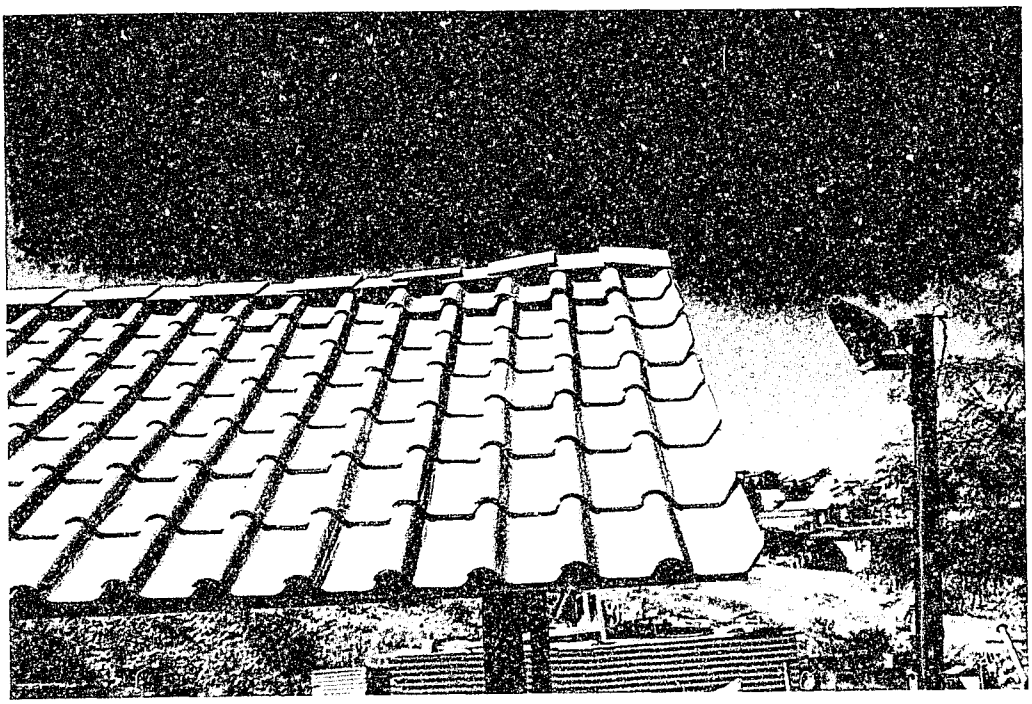


Figure 2: An example of a roof covered with tiles produced by Groupo Sofonias

PLATE 4

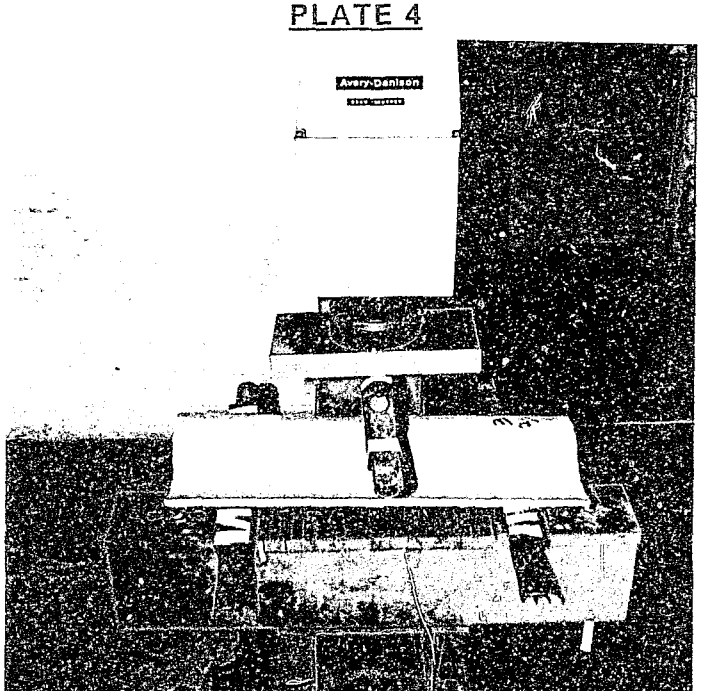


Figure 1: The beam crusher used to establish the transverse strength of the tiles

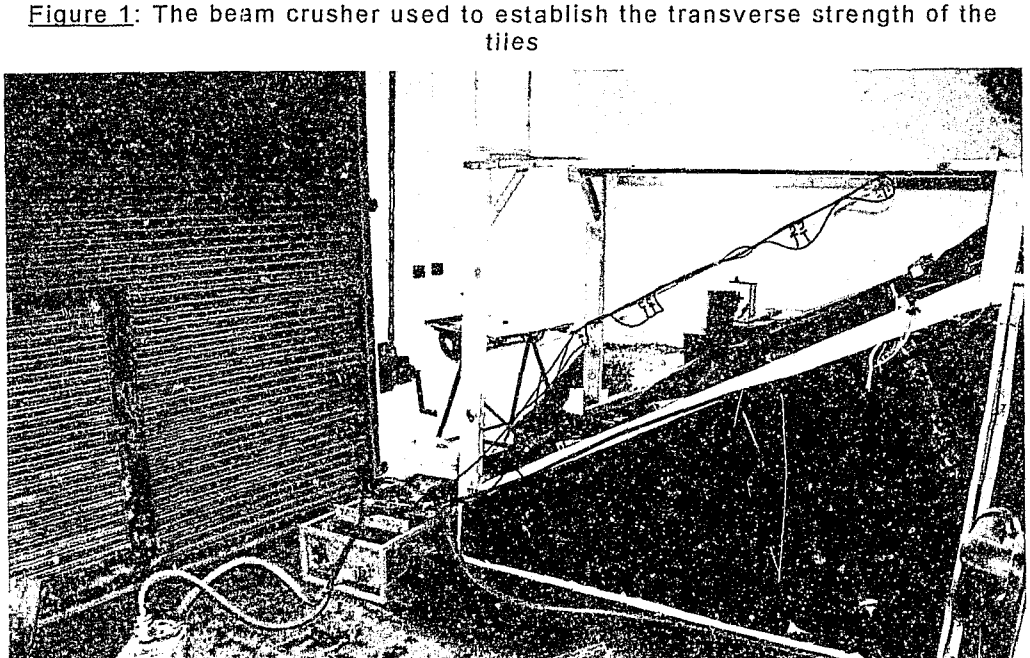


Figure 2: The specially constructed rain penetration test rig

PLATE 5

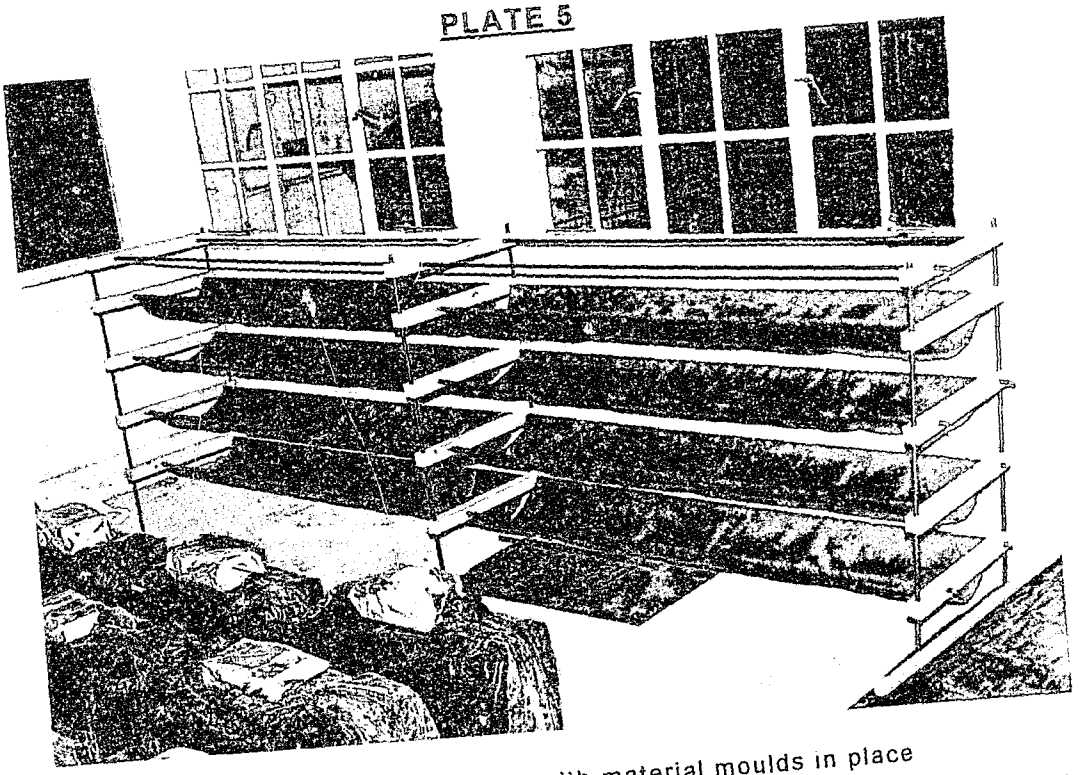


Figure 1: The first frame with material moulds in place

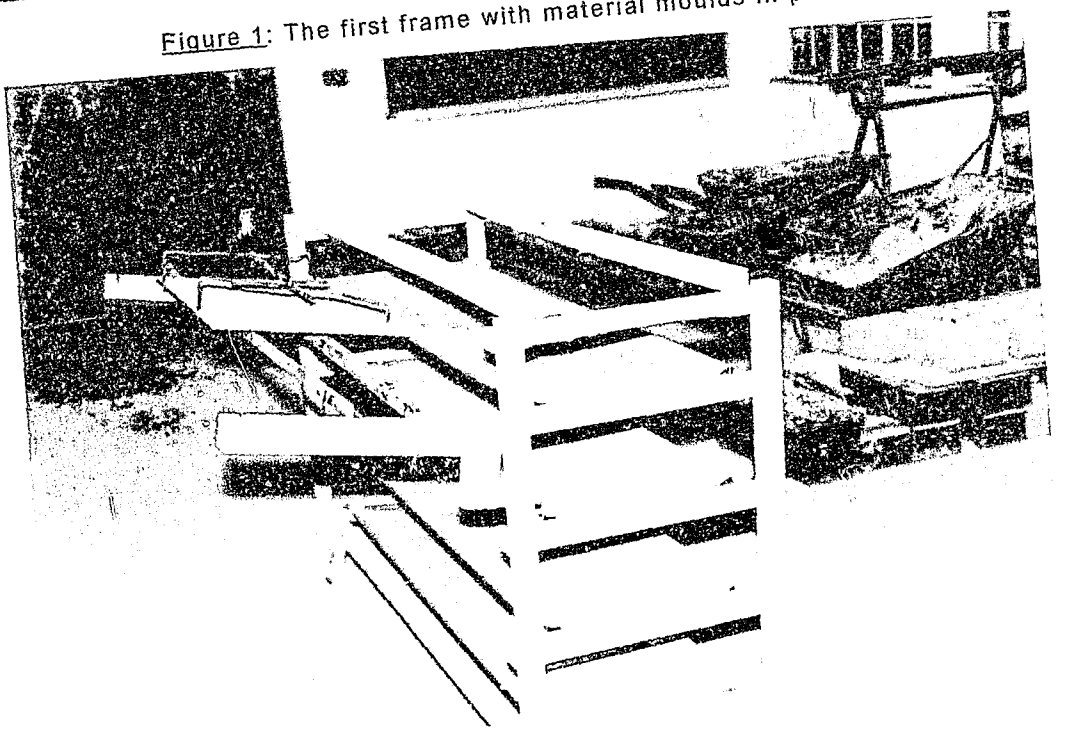


Figure 2: The second frame with material moulds in place. The clamps and angle iron supports, supporting the steel sheet used to transport the tile, can be seen on the side of the frame

PLATE 6

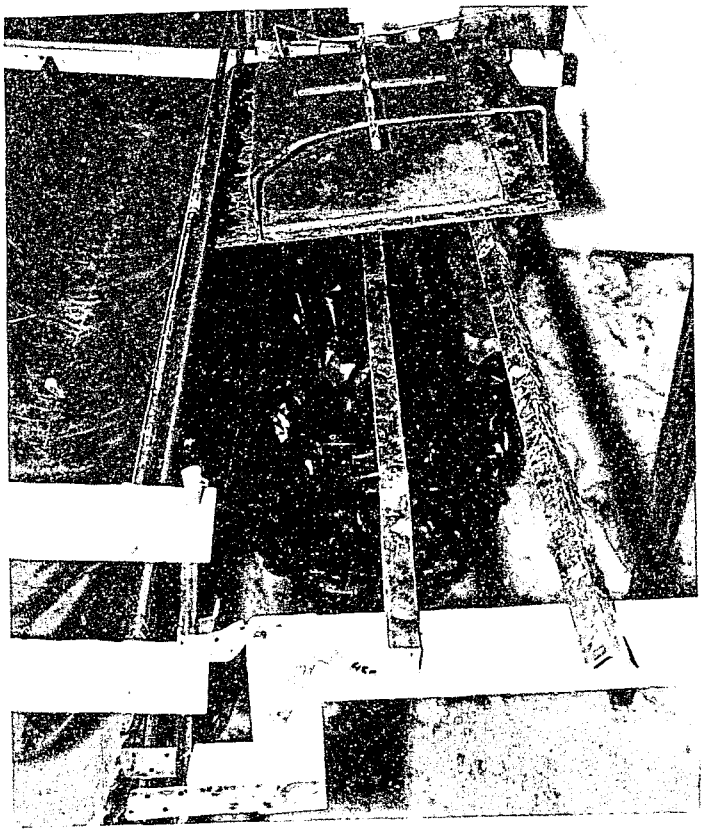


Figure 1: The clamps on the side of the frame supporting the steel sheet on which a green tile waits to be pulled onto the material mould

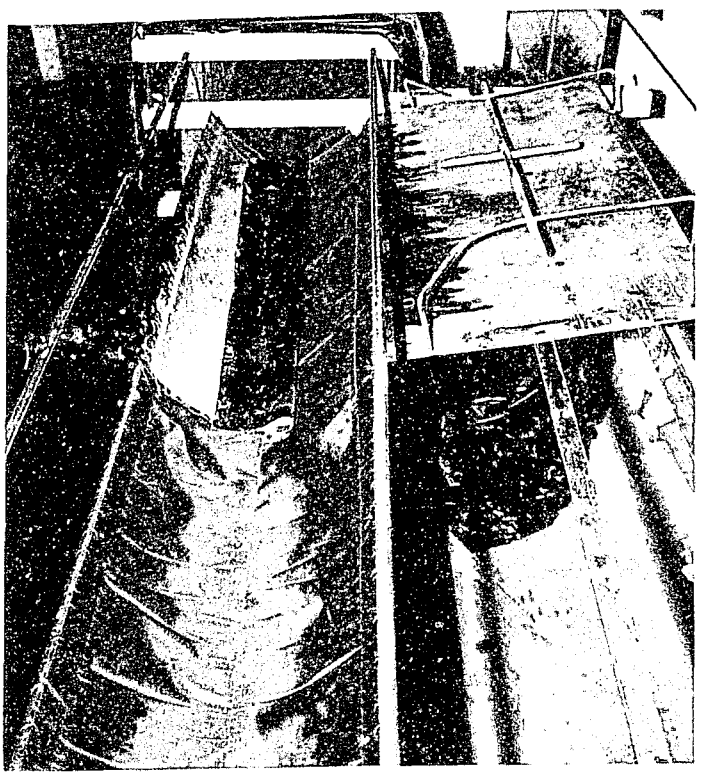


Figure 2: An example of the folding problem experienced with the first frame. This was cured in the second frame by allowing the material mould to be pulled taut, before pulling the tile on to it. The material mould would then be lowered into position with the green tiles in place.

PLATE 7



Figure 1: The various tile profiles tested. Profiles are from the bottom Aa, a, b, c, d and e

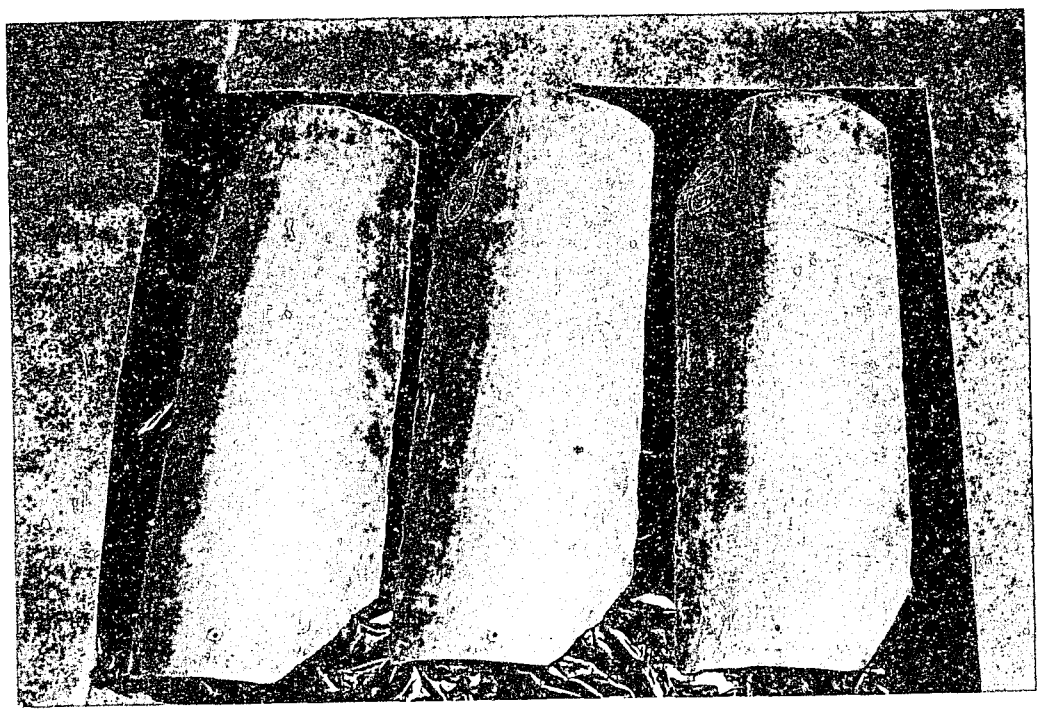
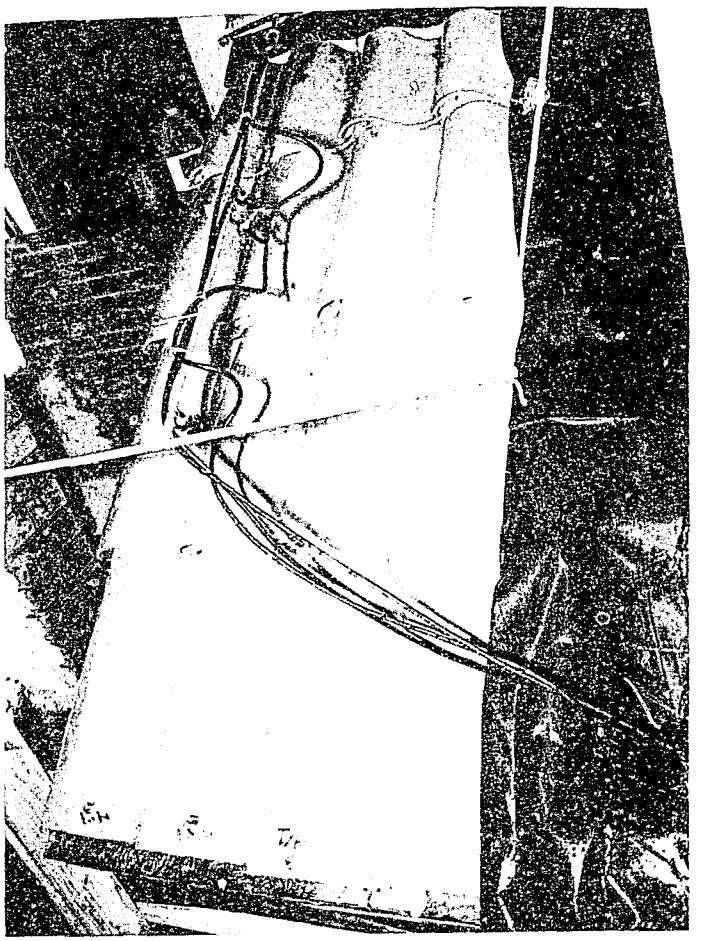


Figure 2: The new parabolic "b" profiled Agri-Tile

PLATE 8

Figure 1: The original Agri-Tiles undergo the rain penetration test



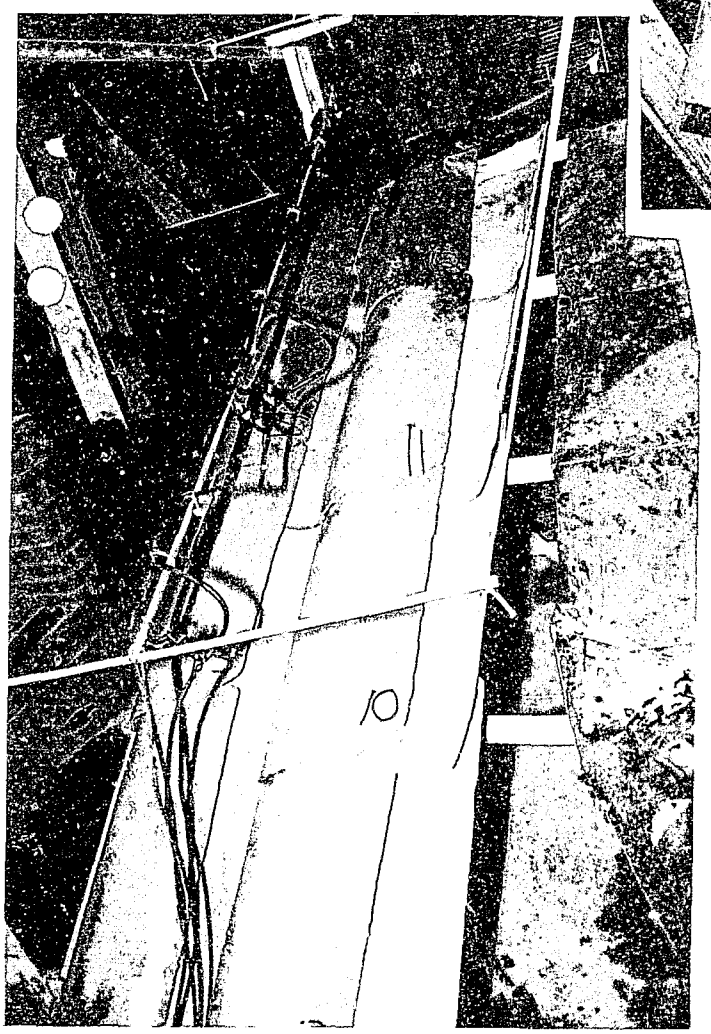
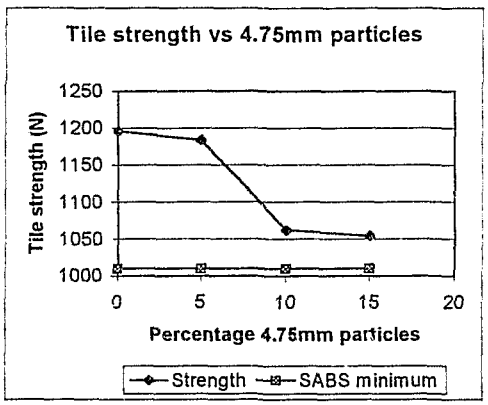


Figure 2: The modified Agri-tiles undergo the rain penetration test

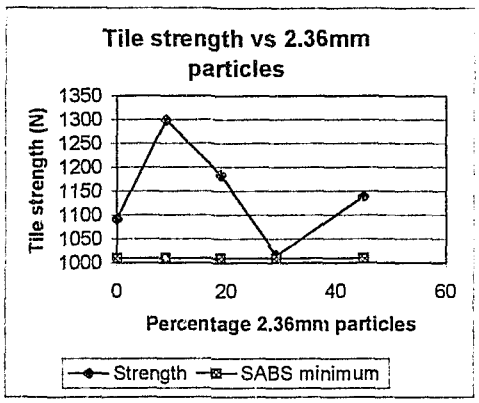
PLATE 9

A summary of graphs 6D to 6I

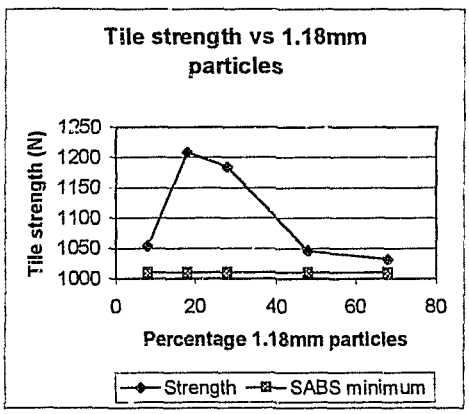
GRAPH 6D



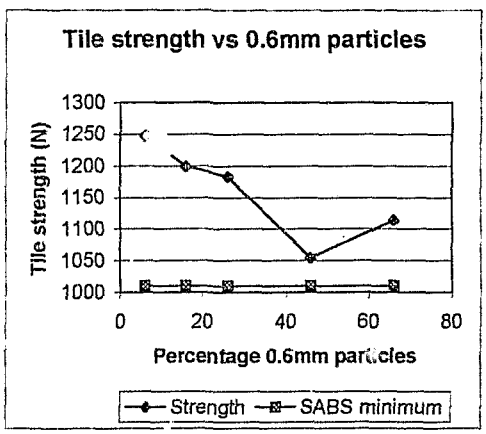
GRAPH 6E



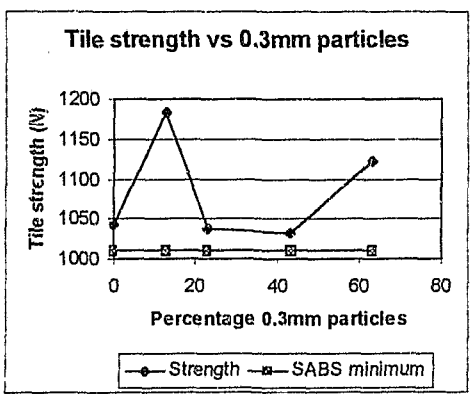
GRAPH 6F



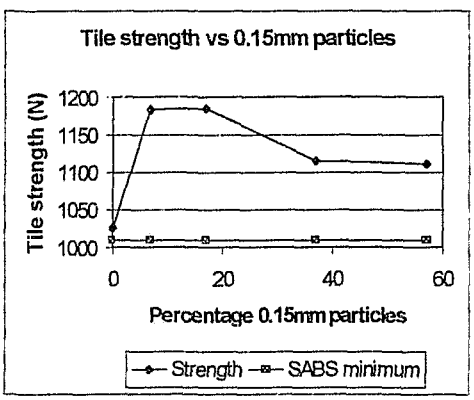
GRAPH 6G



GRAPH 6H



GRAPH 6I



REFERENCES

1) BLAKE E.G 1945 Roof coverings, *Chapman and Hall LTD*
2) MCEVOY M 1994 Mitchell's Building series: External Components, Longman scientific and Technical
3) BATHKE R.M 1996 Alternative Roofing in South Africa, The Concrete Manufacturers Association
4) OWEN R.E *1975 Roofs, The Macmillan press Ltd*
5) CENSUS 1996 Preliminary estimates for the size of the South African population, http://www.css.gov.za/CensRes/prelim.htm
6) NOIR E 1998 Feasibility Assessment for the Development of Micro Concrete Roofing in South Africa, A Report for The Swiss Centre for Development Co-operation in Technology and Management
7) WRATTEN W 1996 Production of a Viable Cement Mortar Roof Tile for low-cost Housing Schemes, Under Graduate Dissertation, The University of the Witwatersrand
8) OLIVERA S 1993 An Expert System for Selecting Roofing Types in Developing Areas, Thesis, The University of the Witwatersrand.
9) LETABA THATCH 1996 Trade Literature
10) HARVEYTILE 1996 Trade literature
11) *ISCOR 1996 Trade literature*
12) PARRY J.P.M 1996 Trade literature
13) ADDIS B.J 1986 Fulton's Concrete Technology, sixth revised Edition, Portland Cement Institute
14) BOND G.W 1946 A Geological Survey of the Underground Water Supply of the Union of South Africa, Government Printer
15) DAVIS D.E 1975 The Concrete Making Properties of South African Aggregate, PhD Thesis, University of the Witwatersrand
16) THE SOUTH AFRICAN BUREAU OF STANDARDS, SABS 1083,

17) DOBSON C 1959 The history of the Concrete Roof Tile, B T. Batsford Ltd

18) MORRIS J & KRUGER R.A 1996 Material Matters in Affordable Housing, International Materials in Housing Conference, Dundee

19) GROUPO SOFONIAS 1997 Noti-Tejas - Information Bulletin for the Latin American Network (may 1997 special edition)

20) ECO BETON Trade literature

BIBLIOGRAPHY

ADDIS B 1995 Cement, Concrete and Mortar, The Portland Cement Institute

THE AGRÉMENT BOARD OF SOUTH AFRICA 1986 Performance Criteria and Minimum Performance Requirements

THE AGRÉMENT BOARD OF SOUTH AFRICA 1993 Minimum Agrément Norms and Technical Advisory Guide

ARRIGONE J.L October 1994 Community Based Organisations, The Develcpment Bank of South Africa

ARRIGONE J.L March 1994 Self-help Housing and Socio-economic Development, The South African Development Bank

C.S.I.R BUILDING TECHNOLOGY Specifications for the Alpha House: An Alternative Approach to Low cost Housing

DAVIS D.E 1975 South African Aggregates, The Portland Cement Institute

DROTSKY J.G 1984 Strengths of Materials for Technicians, Butterworths

FENNER R.T 1989 Mechanics of solids, Blackwell Scientific Publications

GRAM and GUT 1991 Quality Control Guidelines, Element 23, SKAT

HUBBORD, HUMPHRAY and DOMINGO 1975 Squatters: A Report on Some Socio-economic Characteristics of Four Squatter Settlements in Greater Cape Town, South Africa Institute of Race Relations

HYDRAFORM 1996 The Agri-Tile Manual

THE INSTITUTE FOR HOUSING of SOUTH AFRICA 1989 Urbanisation and Informal Settlements, Seminar

MCLEOD D 1993 Development and Application of Building Regulations, The Development Bank of South Africa

MVOKO, V 1998/08/20 Builders Regulation Bill Attacked, Business Day

PATARA S 1994 Transfer of Appropriate Building Technology Through Micro-Entrepreneurs, Cost Housing and Infrastructure, Indian National Academy of Engineers

ROBERG C.W 1993 The Use of Soil-Cement as a Construction Material, Thesis, University of the Witwatersrand

SCHLOSS and NKADO 1995 Cost comparison of a complete roof for an Affordable House. The Cement and Concrete Manufacturers Association

SKAT 1993 Basics of Concrete Roofing Elements

SOIL AND IRRIGATION RESEARCH INSTITUTE 1977 Soil Classification: A Binomial System for South, Department of Agricultural Technical Services

SOUTH AFRICAN BUREAU OF STANDARDS 1990 SABS 542- Concrete roof tiles

SOUTH AFRICAN BUREAU OF STANDARDS 1991 SABS 062- Fixing of Concrete Interlocking Roof Tiles

SWAMY R.N 1988 Natural fibre Reinforced Cement and Concrete, Concrete Technology and Design, Volume 5, Blackie and Son Ltd

WEIDMANN, LEWIS and REID 1990 Structural mechanics, Butterworths Heinemann

TAYLOR W.H 1977 Concrete Technology and Practice, Magraw-Hill Book Company

Author Bathke R M
Name of thesis The Viability Of Manually Producing And Using Concrete Roof Tiles For Low Cost Housing In South Africa Bathke R M 1998

PUBLISHER:
University of the Witwatersrand, Johannesburg
©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.