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DEVELOPMENT OF THE SLURRYBOUND MACADAM CONSTRUCTION TECHNIQUE

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A dissertation submitted the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements of the degree of Master of Science.

Johannesburg, 2012

DECLARATION

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

_____

J. Hattingh

_____ **day of** _____ **2012**

ABSTRACT

The roads sector within the South African civil engineering construction industry has been identified as the sector where significant improvement in job creation can be achieved. As a result, several road construction techniques have been developed over the past decade to satisfy the need for increased labour-intensity.

The Macadam technology has been identified as one of the most appropriate technologies for increased job creation and empowerment of Small Medium and Micro Enterprise (SMME) contractors. Although this is a technology which dates back to the 1700's, it has always been used as a base-layer technology and never used as a surface technology.

Recent application and research work of the Macadam technology has been limited to the layer works of pavement structures. The purpose of this study is to develop the Slurrybound Macadam (SM) technology to such an extent that it can be applied as a surfacing. The research work focuses on:

- the improvement of the construction techniques and equipment used to achieve finishes to tolerances set for conventional machine laid asphalt surfaces and
- the refinement of laboratory test methods to such an extent that Slurrybound Macadams can be designed, specified and tested to the same standard as hot mix asphalt mixes laid by mechanical pavers.

Under the auspices of the author, over 400km of roadway was constructed using the Macadam technology over a period of 10 years. The technology was developed as a labour intensive product suitable for use on low-volume low-speed roads but evolved to a product suitable for high-speed, high traffic volume roads.

The design, specification and laboratory test methods of the Slurrybound Macadam technology have also been reviewed and developed to the norms and standards of a surfacing technology equivalent to hot-mix asphalt layers.

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List of Abbreviations

SMME	-	Small Medium and Micro Enterprise
DM	-	Drybound Macadam
WM	-	Waterbound Macadam
PM	-	Penetration Macadam
CM	-	Composite Macadam
SM	-	Slurrybound Macadam
SABITA	-	Southern African Bitumen Association
GAUTRANS	-	The Department of Public Transport Roads and Works in Gauteng
HVS	-	Heavy Vehicle Simulator
ALD	-	Average Least Dimension
COLTO	-	Committee of Land Transport Officials

1 INTRODUCTION

1.1 Background

The Macadam technology can be considered the predecessor to all modern road building technologies. The Macadam dates back to the 1700's when John Loudon Macadam (1756-1836) used big single sized stones, packed in layers, to form a defined cambered road prism – "a very gentle curve in the cross section" (Reader 1980)

The structural strength of a Macadam pavement is derived from its stone-on-stone frame structure. During the last four centuries this principle has been refined and mechanized into today's road building techniques. Phillips (1995) identified the Macadam technology as one of the most appropriate technologies for increased job-creation and empowerment of SMME-contractors. He found that it is possible to increase employment figures by a factor of 10 for the same unit of expenditure without compromising time, cost and quality.

To satisfy South Africa's need for job-creation this technology has been frequently used on labour-intensive road construction contracts. Most of these applications were limited to the layer works of the pavement structure as Waterbound Macadam layers. Potgieter and Hattingh (1994) developed the composite and Slurrybound Macadam techniques which act simultaneously as a base and surfacing layer (similar to concrete pavements). Over 400km of road network has been constructed using these technologies.

During the course of the above work, related to Waterbound Macadam base coarse, the author identified the need to develop the Slurrybound Macadam technology as a wearing coarse, which had not been done before. Also, that this methodology would generate more employment per unit of expenditure than other wearing coarses. In addition the test methods and specifications have to be generated to norms and standards used in the asphalt industry. This had to be done as part of the research work.

1.2 Overview of fundamental principles of the Macadam Technology

A new generation of Macadam type pavements evolved during the late 1980's and 1990's. The need for job creation and empowerment of SMME's through labour-based road construction projects led to the development of the composite and Slurrybound Macadam construction techniques. Although the traditional Waterbound Macadam techniques were labour-intensive, they were constructed to strict density specifications which could only be achieved through employment of heavy rollers. As such they partially satisfy the empowerment criteria with the exception of the required mechanization level. The new generation Macadam pavements were designed to satisfy the empowerment criteria completely. It was designed to have a low mechanization level, have low skill level requirements and small building element dimensions. With appropriate management, high production rates can be achieved at attractive profit margins. Their wide application potential results in sustainable empowerment opportunities.

Macadam layers derive their strength from a framework structure formed by single sized aggregates, where the voids between these aggregates are filled with a suitable material. The filler material maybe sand, (used in Waterbound Macadams) tar or bitumen (used in Penetration Macadams), and a bituminous slurry (used in Slurrybound Macadams). Recent legislation prohibits the use of tar as construction material due to the health risks it poses.

The various Macadam techniques can be categorized in conventional Macadam-types and a new generation Macadam type. The old techniques are the drybound-, the waterbound- and the penetration Macadam types. The new generation Macadams are the Slurrybound Macadam and the composite Macadam. Figure 1.1 (below) explains the differences graphically.

Drybound Macadam (DM). The coarse aggregate first needs to be placed and interlocked using appropriate heavy rollers. Cohesionless fine filler is then vibrated into the voids without the use of water.

Waterbound Macadam (WM). The coarse aggregate also needs to be interlocked using the appropriate heavy rollers where after water may be used to slush the filler into the voids. The filler may be slightly plastic.

Penetration Macadam (PM). Interlock of the coarse aggregate needs to be achieved using the appropriate heavy rollers after which a hot tar or bitumen is poured over the coarse aggregate layer coating the large aggregates. The voids are not filled completely by the tar or bitumen. Tar may no longer be used due to imposing health risks.

The new generation labour-based Macadam is the slurrybound- and composite Macadam.

Slurrybound Macadam (SM). The coarse aggregates are only orientated by means of light pedestrian type rollers or plate compactors. Because interlock between the aggregate does not need to be achieved, heavy rollers are not required. A slurry, produced from sand and bitumen emulsion, is forced into the voids between the coarse aggregate until the voids are filled, using the same light pedestrian type rollers.

Composite Macadam (CM). Consists of a lower portion of dry- or Waterbound Macadam and a top portion of Slurrybound Macadam.

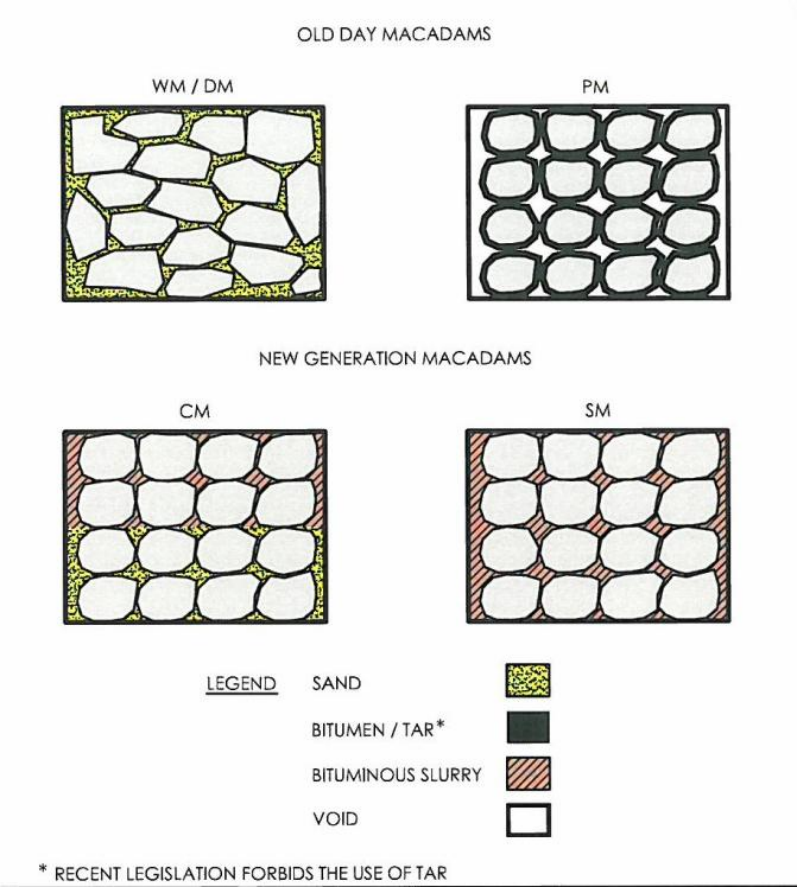


Figure 1.1: Schematic representation of Macadam types

1.3 Research Focus

The purpose of this research is to develop the Slurrybound Macadam technology as a surfacing technology with a focus on the following two main areas:

- **Construction**; namely the improvement of the construction techniques (labour), plant and equipment used to achieve finishes to tolerances set for conventional machine laid asphalt surfaces.

- **Specification and testing**; that is the refinement of laboratory test methods to such an extent that Slurrybound Macadam can be designed, specified and tested to the same standard as hot-mix asphalt laid by mechanical pavers.

1.4 Methodology

The methodology followed in this research was firstly to conduct a literature survey followed by experimental work during which construction methodology, the specifications and testing of the macadam layers according to methods and procedures used in asphalt technology were researched.

1.4.1 Review of literature

The Macadam Technology (aggregate framework with filler material) was until recently only researched as a thicker layer (75mm +) in a pavement structure as base or subbase layer. Macadam layers were not researched as surfacing layers. Nevertheless, the relevant research work was consulted to develop a better appreciation of the behaviour of a macadam layer.

1.4.2 Experimental Work

The aim of the experimental work was to improve the construction process and the construction equipment specifically to comply to norms and standards in the industry; with reference to the structural, functional and aesthetic related aspects. In addition job creation and the empowerment potential were researched. The construction equipment was modified following a critical analysis of the basic activities required to construct a labour intensive Slurrybound Macadam Surface layer. The main activities are the placing, levelling, mixing, compaction, penetration of the slurry, the trimming and the finishing.

1.4.3 Development of laboratory test methods for Slurrybound Macadam Surfacing

Finally, laboratory test methods and procedures were developed to prepare a Slurrybound Macadam briquette to be tested using standard asphalt testing methods i.e. the Marshall Test Criteria. The aggregates in the briquette have to be arranged similar to the arrangements on the road.

2 REVIEW OF LITERATURE AND OTHER SOURCES

2.1 Macadam Technology as surfacing option

The Macadam technology has been well researched over the years and has been identified as a very durable base layer. Of note is the work of Burrow (1975) and Horak (1983). Recently the research work changed focus as the potential of job creation through Macadam construction became apparent. Phillips (1991) identified Waterbound Macadam for base construction as an element where ten times more labour could be employed per unit of expenditure than through current conventional methods.

All the above documents and related research projects were done on the Macadam technology as a base layer in a pavement structure (Visser, Hattingh (1999)). Different finishing techniques which resulted in a more durable surface of the base layer were also applied on an experimental full-scale section near Margate in Kwazulu Natal (Roux and Otte 1993).

The application of the Macadam technology was limited to the pavement layers, mainly base and sub-base, and not as final surface. The development of the slurrybound and composite Macadam in 1995 (Potgieter & Hattingh) resulted in the Macadam technology being used as a combined base and surface layer although the aggregate sizes and testing criteria of Waterbound Macadam base layers were specified. Specifications and testing were not done as for surfacing layers.

In October 2000 the CSIR Transportek released a document titled "Guidelines for the selection, design and construction of Waterbound Macadam base layers". This guideline document was compiled following several research projects inter alia using the Heavy Vehicle Simulator. Note that this guideline document still covers Waterbound Macadam base and not surfacing layers.

This research work introduced the Macadam Technology as a surfacing option. Subsequently SABITA acknowledge this work with the inclusion of the Slurrybound Macadam Seal as an option in *Best Practice for the Design and Construction of slurry seals (SABITA Manual 28)* recently released. The Slurrybound Macadam Technique can now be designed, tested and specified equivalent to hot mix asphalt surfacing applications. The scope for more research work i.e to analyse

the behaviour of a Slurrybound Macadam Layer as surfacing option may now follow.

2.2 Relevance of previous research work

Burrow, 1975: Following the satisfactory performance of roads constructed with Waterbound Macadam base (WBM) layers relative to other technologies (WBM), Burrow conducted a comprehensive analysis of a 3300km network. 1100 Test holes (750mm ø) were augered, materials were sampled and tested, Dynamic Cone Penetrometer tests were conducted and a visual assessment was done. His conclusion was that roads with a Waterbound Macadam base course had given "remarkably superior structural performance compared to "crusher-run" roads." The relevance of Burrows investigation for this research is to note the superior performance of Macadam roads.

Horak, 1983: His research work was done in fulfillment of the requirements of a degree of Master of Science at the University of Pretoria.

The existing material specifications with reference to grading, aggregate strength characteristics and Atterberg limits were compared with samples from several sites. In addition Heavy Vehicle Simulator tests were done on experimental sections of Waterbound Macadams, elastic moduli were determined and structural analysis was done using MECD 3 mechanistic design software. He drafted specifications for Waterbound Macadams and developed a revised density test to accommodate the large Macadam aggregates named the Rondavel Test. The Rondavel Test is based on similar principles to the standard sand replacement density tests. The relevance of his work for this research is the better understanding of Macadam behaviour and its associated failure mechanism.

Phillips, 1991 and 1995: His research work was done in partial fulfillment of the requirements for the degree of Master of Science in Engineering, followed by a Doctor of Philosophy at the Faculty of Engineering, University of the Witwatersrand. Roads with WBM base courses have shown by experience in South Africa to give superior structural performance to roads with crushed stone base courses. He conducted comparative strength tests to substantiate this. He conducted shear strength tests on different sizes of Macadam aggregates to determine average strength parameters of Waterbound Macadam relative to crushed stone layers as previously tested by Maree (1978).

The results of the shear box tests were analysed by simple linear regression (normal stress vs. shear stress) and multiple regressions (normal stress vs. apparent density, flakiness index, grading and degree of saturation). He proved that shear stress increased with increase in stone size, with increase in apparent density, and with improved flakiness index. The degree of saturation had an adverse effect on shear stress.

His tests proved Waterbound Macadam base courses to be stronger than crushed stone base courses. In addition he focused on the creation of employment as a national priority. He recommended appropriate design and labour based construction methods, based on his analysis. Ten times as many unskilled labourers are required to produce Waterbound Macadam base courses than are required to produce crushed stone base courses without having adverse cost implications.

Hefer, 1997: His research work was also done in partial fulfillment of his Master's thesis research. Horak investigated *inter alia* the elastic behavior of Macadam base layers by analyzing Heavy Vehicle Simulator results and in depth deflection measurements. Hefer extended this approach by using the K-mould test apparatus and the Falling Weight Deflectometer.

The K-mould determines the elastic characteristics of the material. All the new generation Macadam types were tested (waterbound, slurrybound and composite Macadams). No significant difference in elastic moduli between the different type of Macadam could be determined. Considering the research by Philips on the stone skeleton, this could have been expected.

Similarly, the Falling Weight Deflectometer was used to determine basins and elastic moduli for both traditional and new generation Macadam pavements. In all instances the Macadam layers were base layers on different pavement support structures i.e. granular or cemented layers. The thicknesses of the Macadam bases also vary considerably.

The E-values obtained during the K-mould study compared well with the back calculated E-moduli determined through the FWD-results. They were in general higher than the E-moduli reported by Horak (1983). Table 2.1 shows the moduli recommended by Hefer.

Table 2.1: Recommended moduli for macadam layers (Hefer, 1997)

Value Description	Over strong cemented layers (C1, C2, C3)	Over weak cemented layers (C4)	Over gravel soils
Mean	860	580	490
Range	450-1500	260-950	150-900
Median	720	600	460
20th percentile	550	420	360

These values were used to draft a design catalogue for Macadam pavements as presented in a Design Manual for labour intensive Macadam pavements (University of Pretoria no date). The Macadam transfer functions for mechanistic analysis was also determined.

Theyse, 2000: The Gauteng Department of Transport and the South African National Road Agency authorized a full-scale Heavy Vehicle Simulator test series on labour-intensive layers near Cullinan (1997). Waterbound Macadam and composite Macadams of various thicknesses were included in this study. Slurrybound Macadams were not included as its development only followed later. The slurrybound technology is not really suitable for base layers because of its higher costs. A Slurrybound Macadam is costly due to the expensive bitumen emulsions used. The composite Macadams were developed to reduce the bitumen content and therefore the costs for equivalent thick base layers. These test sections were constructed by emerging contractors using only light compaction equipment. Sub-standard densities were obtained.

The following is a summary of Theyse's (1997) conclusions as reported in McCutcheon & Taylor Parkins (2003:105).

> The Heavy Vehicle Simulator was used on test sections and both the elastic and permanent deformations were measured using Multi-depth Deflectometers. The loading regimen applied to the pavements was as follows:
>
> - 200 000 repetitions of a 40 kN dual wheel load with the pavement at equilibrium moisture content.
> - 200 000 repetitions of a 70 kN dual wheel load with the pavement at equilibrium moisture content.

- 100 000 repetitions of a 70 kN dual wheel load with water entering the base layer through core-holes drilled into the base layer.

It was found that the 100mm layer of poorly compacted Waterbound Macadam (80.1 percent apparent density) had a rut rate of only 0.7mm/million applied 40 kN loads. If it was used to predict a 10mm-rut depth it is found that 13.3 million 40 kN-load repetitions (E80's) would be required. For the 150mm layer which had an even lower apparent density (78.4 percent) the deformation rate was found to be 1.3mm/million 40 kN wheel loads and for a 10mm rut depth 11 million repetitions would be required.

While it may seem surprising at first that the thicker layer shows poorer performance, if one considers the densities achieved for the two layers the reasons for this become clear. Since the 150mm layer had a lower density it showed more densification and thus more rutting.

The following should be kept in mind when considering these rut rates: The Macadam layers had a density of only 80.1 percent of the bulk density which is much lower than the 88-90 percent required for Waterbound Macadam 1 and 87-88 percent for Waterbound Macadam 2 according to TRH4 standards. This resulted in higher rut rate measured compared to what can be expected from Waterbound Macadam layers compacted to specifications. These rut rates should therefore only be considered representative of layers constructed using light equipment. Having said this though, these tests definitely agree with the other experiences of Waterbound Macadam. Despite their poor compaction it is estimated that these layers could have carried 10 million E80's. This would make these layers suitable for heavily trafficked roads and even better performance can be expected if higher compaction densities were achieved.

For the composite Macadam layers investigated in this study the results were less positive. These layers whose in-situ densities were also far below specifications had relatively high rut rates. As is conventional with composite Macadam layers, the coarse aggregate size of the top (Slurrybound) layer was smaller (26mm) than that of the bottom layer

(53mm). The bottom layer was filled only to approximately $^2/_3$ with fines. Then the layer with smaller coarse aggregate was placed on top and the other third of the voids as well as the voids in the aggregate were filled with slurry. These layers were also compacted with plate vibrators and BOMAG 76 pedestrian rollers. The apparent density of the 75mm layers was 70.4 percent and that of the 125mm layer was 80.1 percent.

The rut rate found for the composite Macadam was 1.9mm/million repetitions of 40 kN for the 75mm layer and 4,0mm/million for the 125mm layer. These rut rates are clearly higher than those of Waterbound Macadam. It should furthermore be pointed out that both the labour and material costs of composite Macadam are higher than for Waterbound Macadam.

The above results are summarised below in Table 2.2

Table 2.2: Summary of performance of Macadam layers as tested by the Heavy Vehicle Simulator (Cullinan, 1997)

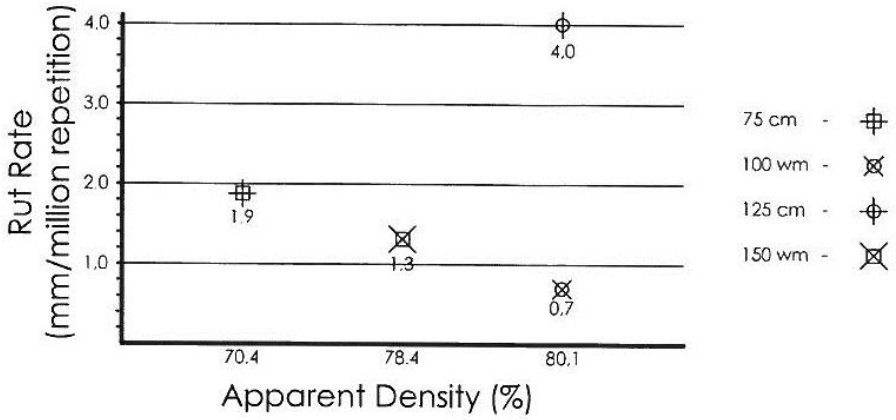
Macadam Type	Apparent Density (%)	Thickness (mm)	Rut Rate (mm/million 40kN repetition)	E80's to achieve 10mm rut depth in millions
Waterbound (wm)	80,1	100	0,7	13,3
Waterbound (wm)	78,4	150	1,3	11
Composite (cm)	70,4	75	1,9	Not reported
Composite (cm)	80,1	125	4,0	Not reported

In summary the work by Theyse reveals:

- That the lower the densities for the Waterbound Macadam layers, the higher the rut-rate.
- The thicker Waterbound Macadam Layer, (150m versus 100mm) recorded less E80's to achieve a 10mm rut depth.
- That the rut rates recorded with the Composite Macadams are higher than those of the Waterbound Macadams.
- The thicker layers of both the Waterbound Macadam and the Composite Macadam surprisingly achieved less cummulative E80's than the thinner layers due to the higher densities achieved with the thinner layer in case the of the Waterbound Macadams.

All these conclusions seem to be in order. However, with the Composite Macadam, the thinner layer also had a lower density (70,4%) but the rut rate (1,9mm/million repetitions) was better than the denser thicker layer million repetitions as shown in Figure 2.2.

Figure 2.2 Rut Rate against apparent density



The 125mm thick Composite Macadam is considered an outlier.

This can be explained due to the fact that a shear-plane developed between the bottom Waterbound Macadam part and the top Slurrybound Macadam part of the Composite Macadam.

The aggregates of the thinner layer were better interlocked than the thicker layer and will prevent the formation of shear planes. The initial density tests will not accurately reflect the extent of orientation, interlock or densification but will merely indicate the degree to which the voids were filled with sand or slurry.

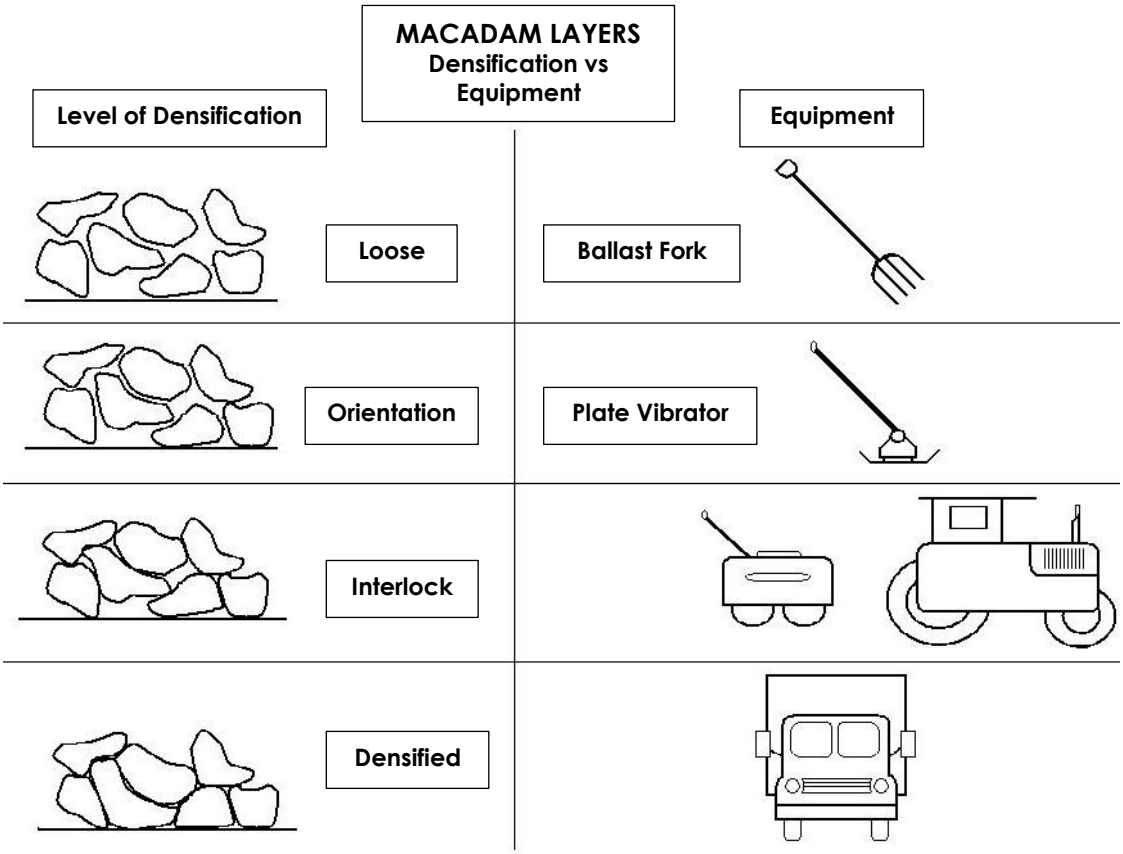
Orientation, interlock or densification is a function of the compaction effort whilst density is more a function of the extent of to which the voids were filled. Clearly, density is of lessor importance if the development of the rut rate is compared against the degree of aggregate framework (orientated, interlock or densification)

This research programme highlights the importance of achieving sound interlock.

Creating a strong frame is the most important factor governing the performance of waterbound and composite macadam layers.

The theory developed by Potgieter Hattingh & Schultz that densification of a Macadam happens in three distinct phases namely, orientation, interlock and densification is shown in Figure 2.3.

Figure 2.3 Different stages towards densification



3 EXPERIMENTAL WORK

The first focus point of this research was to improve the construction technique to achieve finishes within tolerances set for conventional machine laid asphalt surfaces. In this chapter this focal point is addressed.

3.1 Recent developments with reference to construction techniques

Over 400km of roads and streets were constructed under the auspices of the author since 1994. The complete list of roads is shown in Appendix II.

Analysis of the specified thickness of Slurrybound Macadams (SM) gives an indication of the gain in confidence amongst engineers with the specification of SM-layers. The initial layers were constructed to a thickness of 125mm (Taxi Bay in Randfontein – 1994) and with the gain in confidence, due to its excellent performance, gradually reduced to a thickness of as little as 15mm (Lerato near Pilgrim's Rest – 2003).

Apart from the work of the CSIR (Roux & Otte, 1993) where slurry was used to improve the surface integrity of a Waterbound Macadam base and a taxi bay in Randfontein (Hattingh 1993), the first full scale Slurrybound Macadam pavement was constructed in Baragwanath Hospital by Potgieter and Hattingh (1995). The thickness of this layer was 75mm, with railway ballast (37mm) as coarse aggregate. The layer was simultaneously a base and surface layer.

The layer was designed as a Waterbound Macadam layer but the filler sand was replaced with a bituminous slurry. A similar design philosophy was followed with the construction of bus bays in Mohlakeng (1995) where the voids in a 125mm thick Macadam layer were filled with a bituminous slurry. Although the job-creation potential of this new technique drew the attention of the industry, the cost benefit in replacing filler sand with a bituminous slurry was not attractive. Thus, the costs had to be reduced and a street was constructed in Doornkop (Soweto, 1995) where the bitumen content in the penetration slurry was reduced from a nominal 230ℓ / m³ to 150ℓ / m³. The aggregate size was 37mm and the layer was constructed to a thickness of 75mm. The bitumen emulsion content on the final slurry, applied in the surface, was still determined using the Cape method Method CS in TMH1 (CSRA, 1986). This work was done for the Johannesburg Road Agency under auspices of Dr Emile Horak, managing director. As mentioned above in

Section 2.2 Dr Horak conducted his master thesis on Waterbound Macadam pavements.

The contribution of the reduced bitumen content in the penetration slurry was suspect as premature cracking appeared on the road surface. This experience led to the logical conclusion that the penetration slurry needs to be designed to achieve maximum stability; but the thickness should be reduced to contain costs. The composite Macadam was introduced where the bottom two thirds of the Macadam layer was constructed in accordance with the waterbound techniques and the top third in accordance with the Slurrybound Macadam technique (Doornkop Soweto, 1996).

This pavement layer was considered a success and was widely awarded by the industry. A list of the awards is attached in Annexure I. At least 100km of street network was constructed using the composite Macadam base layer to a thickness of 75mm with the Slurrybound Macadam forming the top 25mm. These layers are still performing extremely well all over township street networks in South Africa. Given the traffic loads on the network where this labour-based technology was seen fit for use, a problem arose in that the structural strength of a composite Macadam is much higher than that required for the actual traffic loading and is thus not really cost effective for use on a tertiary road network (Mamelodi, 1997; Kwa-Thema, 1998; Mashishing, 1998). Subsequently the composite Macadam fell into disfavour.

The Department of Public Transport Roads and Works in Gauteng (GAUTRANS), conducted Heavy Vehicle Simulator (HVS) tests on Macadam pavements constructed along labour-based principles near Cullinan (1997) (Rust, 1997). This was a very expensive testing programme which contributed significantly to a better understanding of the performance of Macadam layers. It was concluded that the thinner, better compacted layers showed superior resistance to rutting than the thicker poorly compacted layers. The specified density of a Waterbound Macadam layer had a significant influence on the ultimate performance of the layer. Although the better performance is a result of interlock achieved through the higher compaction effort and not necessarily the achieved density. The recorded density will reflect the extent to which the voids between the coarse aggregate are filled and not necessarily the compaction effort. The thinner Slurrybound Macadam layers were developed as a result of this test work. To date

Slurrybound Macadams have not been exposed to simulator accelerated loading tests.

The Slurrybound Macadam (SM) was specified as surfacing *inter alia* in Mamelodi, 1997 (Pretoria), Atteridgeville, 1997 (near Pretoria) and Mashishing, 1998 (Lydenburg). A minimum thickness of 50mm was specified on these roads. The SM roads performed extremely well under traffic and the thickness was further reduced to 25mm in Kagiso, 2000 (Krugersdorp) and eventually to 15mm at Leroro near Bourke's Luck, 2000 in Mpumalanga. This reduction in thickness was motivated on grounds of excellent performance.

As can be seen from the above, the construction technique developed from a relatively thick (125mm) base layer, to a composite layer (base and surfacing) and using the same construction principles, to a surfacing layer (15mm).

This research work was done to elevate this construction technique to a surfacing technique on par with industry norms, specifications and test methods (McCutcheon, Croswell, Hattingh (2006)).

3.2 The Construction Process

In essence the Slurrybound Macadam construction technique is constructed in three major steps, firstly to place the single-sized stone aggregate, secondly filling of the voids with cold bituminous slurry using vibratory equipment and finally the layer is finished to comply with specifications.

Unlike the other Macadam construction techniques, the complete Slurrybound Macadam layer can be constructed using light equipment only. Due to the size and shape of the coarse aggregate, densification on Waterbound and composite Macadams necessitates the use of heavy rollers to meet the specifications. Interlock will not be achieved without the compaction effort of the heavy rollers.

In addition, the layer and associated construction process has to satisfy the required goals from the following viewpoints:

- Structural goals
- Functional goals
- Aesthetical goals
- Job creation goals

- Empowerment goals

From a structural viewpoint the main goals to achieve would be:

- Stone-on-stone contact of the coarse aggregate.
- Orientation of the coarse stones.
- Proper penetration of the bituminous slurry.
- Dense or close surface texture of the layer.
- Mix design suitable for traffic and environmental conditions.
- Surface, free of undulations or surface irregularities.

From a functional viewpoint the main goals to achieve will be:

- Surface within the required lines and levels.
- Surface free of undulations or bumpy joints.
- Surface free of irregularities.
- Suitable texture w.r.t. skid resistance, and mist-spray caused by traffic in wet conditions and a lack of texture.

From an aesthetic viewpoint the main goals to achieve will be:

- Uniform fresh black colour without stains.
- Texture in accordance with community needs.

From a job creation and empowerment viewpoint the main goals to achieve will be:

- Low mechanization level
- Attractive production rates
- Ease of establishment
- Prompt accommodation of traffic
- Ease of construction

Unlike the other Macadam construction techniques, the complete Slurrybound Macadam layer can be constructed using light equipment only. The degree of interlock on Slurrybound Macadams is less due to the superior properties of slurry filling the voids if compared with the filler used in Waterbound Macadams.

The degree of interlock required on waterbound and composite Macadams necessitates the use of heavy rollers.

Construction of any labour-intensive road pavement layer requires a holistic approach where goals are set from different viewpoints namely structural, functional, anesthetic, job-creation and empowerment.

3.2.1 The construction process: structural related aspects

3.2.1.1 The selection of the correct stone sizes

The selection of the correct stone sizes is of cardinal importance. Phillips (1990) concluded that with an increase in stone size the shear stress increases. Thus, the maximum stone size had to be determined for a particular layer thickness without introducing other modes of distress different from shear failure i.e. ravelling. The volumetric principles within the layer have to be satisfied. This is best achieved if a stone size is determined where the Average Least Dimension (ALD) - Test Method B18(a)/b TMH1 (CSRA, 1986) equals the layer thickness divided by three (ALD = $\frac{t}{3}$ where t is the layer thickness). If the stones are too big, these will not form a structural framework in the layer and the individual stone will be unstable under loading, albeit with high resistance to shear failure. This may be illustrated in Figure 3.1.

It illustrates the following:

- Stone too big to present stone on stone frame stability
- Gap between stone pinnacles too large exposing the slurry to stresses and subsequent cracking
- Stones tend to rock in slurry matrix which will eventually result in cracking, raveling and potholes
- Void content too high (costly)

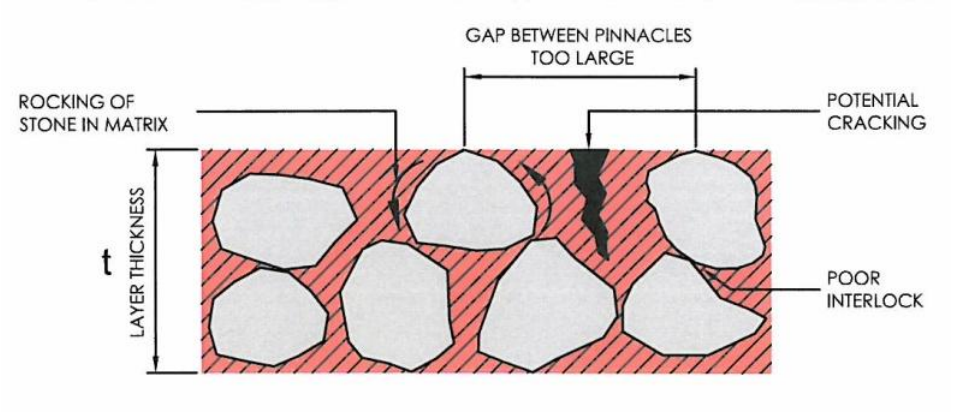


Figure 3.1: Selection of the correct stone sizes: stones too big

An example of a road constructed (1996) in which the aggregates were too large is Ring Road; Doornkop, Soweto, between West Avenue and South Road. See Photo 3.1.



Photo 3.1: Ring road constructed with too large aggregates. Note the cracks around the stone pinnacles. Secondary distresses, ravelling and potholes also visible.

If the stones are too small the layer will have very poor resistance to shear failure. These principles can be best illustrated in figure 3.2.

It illustrates the following:

- Reduced shear strength
- Instability during construction
- Too little voids for slurry penetration

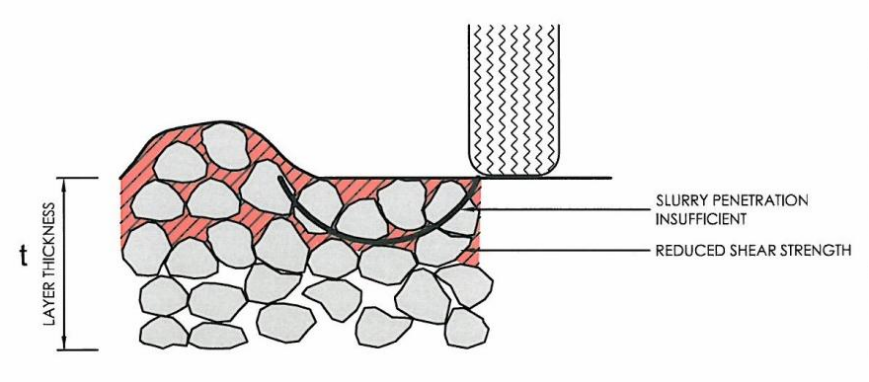


Figure 3.2: Selection of the correct stone sizes: stones too small

The functionality of the correct stone size is illustrated in figure 3.3. It can be seen that:

- Dense surface achieved
- Stone stability achieved (horizontally orientated)
- Sufficient voids for slurry penetration
- Stone-on-stone frame stability achieved

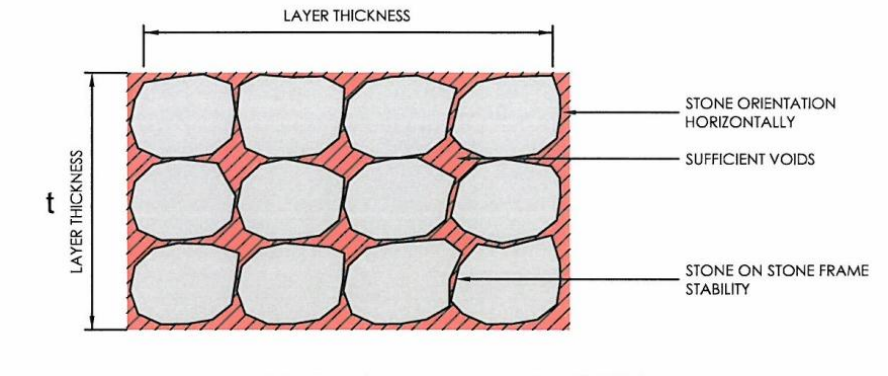


Figure 3.3: Selection of the correct stone sizes: Ideal stone size (t = ALD x 3)

3.2.1.2 (b) Placing, levelling and compaction

The coarse aggregates must be placed, levelled and compacted in separate activities. Several on-site experiments were conducted where the coarse aggregates were mixed with the bituminous slurry (in concrete mixers) prior to placing, levelling and compaction. This was not successful due to segregation during placing and lack of stone-on-stone contact in the completed layer. It was observed that too many stones were orientated along their vertical axes instead of the horizontal which reduced the stability of the layer. In addition the mixing process was unnecessarily extended because of the large volumes of stone which need to be mixed in comparison with separate placement of the stone.

The extent of care taken during the initial steps will eventually determine the degree of accuracy achieved with reference to the specified tolerances of the layer. It is therefore important to place and level the coarse aggregate using guide rails and levelling beams. As the levelling beam together with the guide rails will also be the final template against which the wet slurry will be placed its fitting needs to be precise during the early stages. If not, it will not be possible to use this template (beam and rail) at a later stage. The sizes of these rails and beams must be such that it is easy to handle but rigid and strong enough not to buckle or deflect. Rakes and ballast forks are the best to spread and level the single sized aggregate.

The following diagrams best explain this principle. Figure 3.4 shows the rigid template formed between the guide rails and the beam

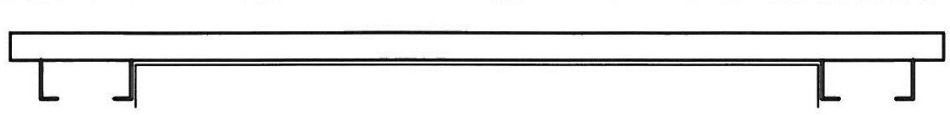


Figure 3.4: Template formed by beam and rail

In Figure 3.5 the effect of poor template fittings are shown in either an overfill or underfill situation.

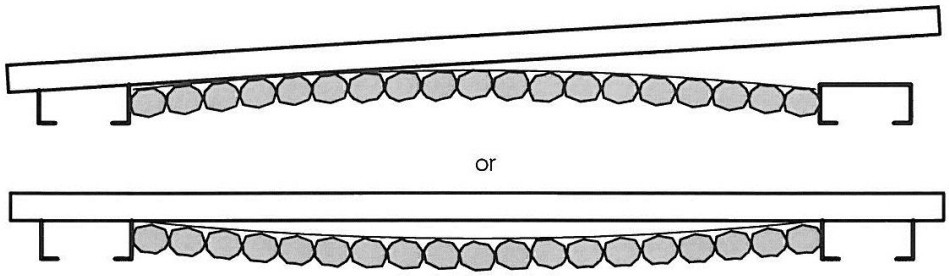


Figure 3.5: Examples of poor template fittings

The following photographs illustrate good practice:



Photo 3.2: Initial template trimming



Photo 3.3: Spinning beam on guide rail



Photo 3.4: Spinning beam as final template

The finishing techniques explained above have been patented by the author (Annexure IV).

With a Slurrybound Macadam layer the required densities (see later research) can be achieved using light pedestrian type rollers or plate vibratory equipment only. The bituminous slurry has a high workability and will fill the voids with a relatively low

compaction and vibration effort. This is not the case for composite Macadam and Waterbound Macadam layers which require a heavy compaction effort to achieve stone interlock and filling of the voids. The compaction efforts required on a Slurrybound Macadam layer is merely to orientate the single sized stone aggregate and to penetrate the bituminous slurry and not to achieve interlock.

Unfortunately the narrow widths of these pedestrian compactors caused surface irregularities and undulations due to shear movement of either the stone or the slurry or the mix as shown in figure 3.6.

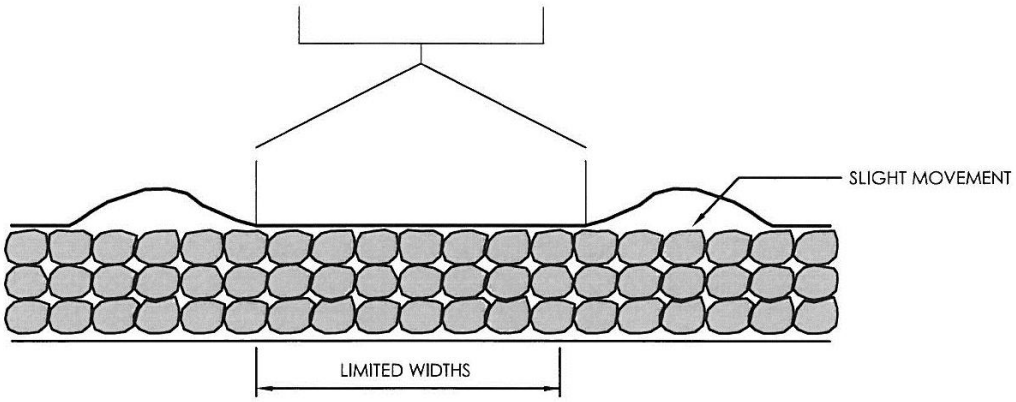


Figure 3.6: Surface irregularities due to limited widths of pedestrian rollers or plate vibrators

Once the single-sized aggregate had been placed and levelled using the guide rail and levelling beam as template the aggregate needed to be orientated by means of either a light walk behind drum roller or a plate vibratory compactor. A single pass with this equipment was sufficient to achieve the necessary orientation.

The slurry was mixed separately, placed and levelled on the orientated stone. The guide rail remained in place. The thickness of the spread slurry was sufficient to fill the voids. Over-application of the slurry causes the stone to float in the slurry, breaking the stone matrix and forming surface irregularities. The roller or plate vibratory compactor must then be used to penetrate the slurry. A number of passes was required and each pass slightly overlapped the next pass. More than one roller / compactor was necessary per team. The slurry was allowed to break, where after all ridges, clots and irregularities were trimmed using a flat shovel. The coarse aggregates were slightly exposed and the levelling beam cleared the surface with at least 3mm. This was due to the orientation of the aggregate and

the filling of the voids. The guide rails were cleaned while the slurry was still fresh. The surface was checked again using the template (guide rail and levelling beam). This being the final opportunity to correct any undulations (see Fig. 3.7).

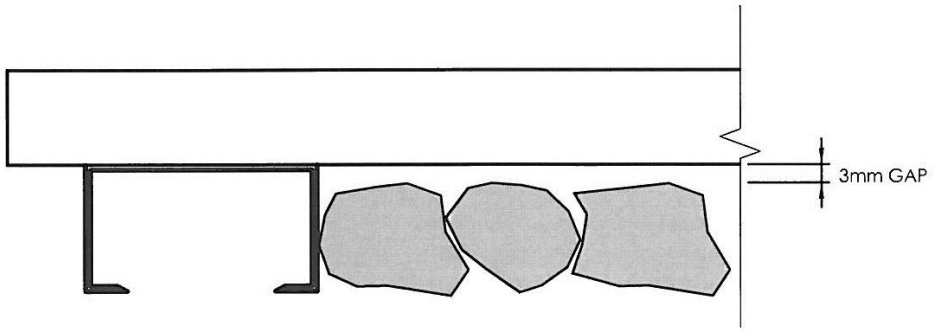


Figure 3.7: Template check after slurry penetration

The surface was then ready for application of the final slurry. The guide rails remained in place.

3.2.1.3 (c) Mixing, penetration and finishing of the slurry

Prior to this research work the Slurrybound Macadam layer was designed as a mixture of layer technology and seal technology. The slurry was designed and tested separately using Method CS - TMH1 (CSRA, 1986) 80/100 penetration grade bitumen. Once the optimum nett-binder content was determined the 80/100 penetration grade bitumen was substituted with an equivalent nett-binder content of a 60% stable grade bitumen emulsion. This research work changed the mix-design process completely in that the briquettes are prepared using the bitumen emulsion with the filler sand and the coarse stone matrix. The new procedures were determined through an extensive series of experiments as part of this research work.

It is important to note that the optimum binder content and cement content is determined in the slurry-mix. The complete Marshall-criteria is analyzed to determine the binder content whilst the cement content is more influenced by the required immersion index (an immersion index of 75% is specified) and the time period required to keep the slurry-mix workable especially for labour-intensive application.

The workability or consistency of the slurry is determined using the Cape Cone Slump Test - Method CPA / C1 (CPARD, 1993). The flow plate was replaced by a plastic laminated sheet. The ideal consistency to achieve easy and prompt penetration without segregation was tested according to the above methods. The main variable in improving the consistency is the water content. Normally the addition of water will increase workability to an extent where segregation or wash-out will be noticed. The amount of water to be added will differ from time to time as moisture in the sand stockpiles varies. Sand from different geological parent rock will also behave differently. Rock-types with a lower relative density (i.e. granites / dolorites) will present easier workability and consistency than the sand crushed from the heavier rock types (i.e. andesite).

Should wash-out or segregation be noticed with the addition of water before a consistent mix is achieved the cement content may be slightly increased. Several experiments were conducted using the Cape Cone Slump Test and the ideal flow for easy penetration was determined to be between 50mm and 70mm.

The modified equipment is shown in the following pictures.



Photo 3.5: Cape Cone Slump test with modified flow plate



Photo 3.6: Cape Cone Slump test with modified flow plate



Photo 3.7: Cape Cone Slump test with modified flow plate

The slurry can be either mixed by hand or using a mobile concrete mixer. Should the slurry be mixed by hand, mixing must be done either on the completed base layer or a designated area but not on the completed Slurrybound Macadam layer.

Once the slurry is mixed it may be carted in wheelbarrows on walking boards laid on the prepared stone layer. Tipping and spreading must be done with care not to disturb the stone layer. The thickness to which the slurry must be spread prior to penetration is calculated on the principle that the voids to be filled amounts to approximately 40% of the volume of the completed Slurrybound Macadam layer. The following spreading thicknesses are recommended.

Table 3.1: Recommended application rate of wet-slurry prior to penetration

Layer thickness (mm)	Application rate m^3 / m^2
15	0.006
20	0.008
25	0.010
30	0.012
35	0.014
40	0.016

It is important not to exceed the above recommended spreading rates due to the possibility that the aggregate will float in the surplus slurry resulting in either lack of stone on stone contact and irregularities. Overfilling is a general mistake as contractors and supervisory staff want to ensure that there is sufficient slurry to penetrate the voids.

Penetration of the slurry can be easily monitored during the execution of the works by digging a little hole in the fresh layer. If the aggregates are not completely coated (especially the bottom part) penetration is not yet successful and more vibratory passes will be necessary. The penetration of the slurry can later be determined through core-drilling. At least four weeks need to lapse before the core may be recovered (too late to rectify poor penetration). Should poor penetration be noticed the following main factors may have contributed thereto:

- Use of the wrong compaction equipment (high frequency plate vibrators preferable).
- Insufficient vibratory passes.
- Dirty stones.
- Compaction or penetration occurring too late. The slurry had already set.
- Insufficient voids in the stone matrix due to either the wrong stone size, flakiness or gradation not complying with the specification.

3.2.2 The construction process: functional related process

Although the ultimate performance and life span of the Slurrybound Macadam layer depends largely on the structural aspects, the functional aspects also contribute thereto. Studies by others proved that riding quality and life span is directly related.

In addition efficient surface water drainage will also be achieved if a layer is constructed free of undulations and surface irregularities. The result will be less ponding or puddles with the reduced risk of moisture penetration into the pavement layers.

Normally the texture on any final slurry layer tends to be rather smooth if compared with other surface types like stone seals. Due to the relatively low stability of bitumen slurry layers the layers are prone to bleeding. The application rate of final slurry layer must therefore be limited. The final slurry must not be used to iron out undulations or irregularities. This must be achieved through proper construction of the coarse aggregate.

The extents to which the slurry must be applied are shown in the following sketches.

If the slurry application is too low the coarse aggregate will be exposed resulting in high degree of permeability as shown in figure 3.8.

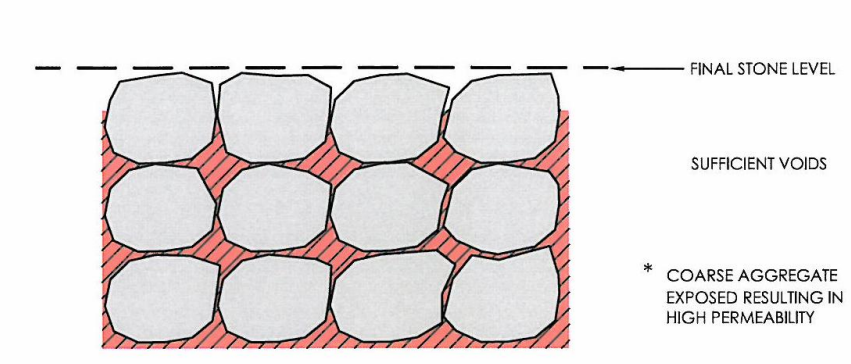


Figure 3.8: Slurry Application too low

The correct application will be such that the coarse aggregate are covered with a maximum slurry thickness of 6mm as shown in figure 3.9.

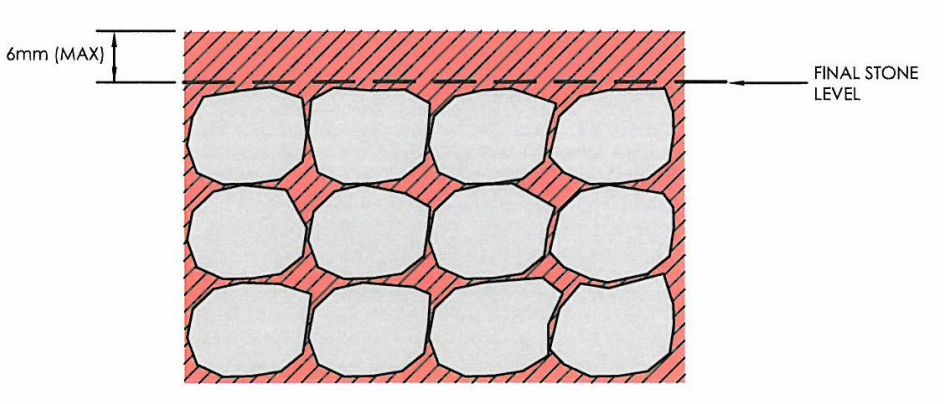


Figure 3.9: Recommended Slurry Application

Should traffic or environmental conditions require a different texture the following may be considered:

- Application of a coarse slurry as final slurry.
- Application of a stone single-seal as final surfacing.

The design and application of conventional single stone seals are well-researched and documented especially for nominal stone sizes of 6.7mm; 9.2mm and 13.2mm (SANRAL, 2007).

The scope to use pre-coated 4.75mm or 6.7mm aggregate with or without a bitumen binder as tack coat on a Slurrybound Macadam layer needs to be further researched as it may solve several surface texture problems associated with the Slurrybound Macadam technique. In particular an improved texture with associated skid-resistance and reduced mist-spray under traffic is required. From an aesthetic viewpoint the layer can be offered without stains associated with slurry works and will compare favourable with hot-mix paver laid asphalt layers.

If the Slurrybound Macadam layer is constructed in accordance with the specification with reference to line and levels with a high level of workmanship, the layer will be free of undulations and surface irregularities and will offer efficient drainage (no ponding) and a high riding quality.

The layout of construction joints must also be done cleverly to ensure a smooth riding. Construction joints orientated at an angle of 15° will reduce the effect of a bumpy joint and enhance a smooth riding experience. This joint-layout is essential for high speed roads.



Photo 3.8: High speed cambered provincial road constructed using a Slurrybound Macadam surface (Koffiefontein/ Oppermansgronde – Free State Province)

3.2.3 The construction process: aesthetic related aspects

3.2.3.1 (a) Colour variances

Being a relatively new construction technique communities tend to compare the final product with hot-mix paver laid asphaltic layers. Because it is a labour-intensive technique it is considered inferior and is very harshly judged in its aesthetic appearance in particular the lack of an even uniform finish black colour in the early days after completion.

The variance in black colour is a direct result of slight variances in moisture in the slurry mix. Within a few months and after traffic the colour differences will disappear and only an experienced eye will notice the difference between an asphalt or a Slurrybound Macadam layer. During the 2003 Pavement Management Survey (conducted along TMH 9 principles) of the Johannesburg Roads Agency network most of the Slurrybound Macadam surfaces were recorded by the surveyors as asphalt surfaces.

Irrespective of the above it may be advisable to either apply a bituminous fog spray on a newly constructed Slurrybound Macadam layer or alternatively apply a single seal.

The Slurrybound Macadam Technology is also ideally suited for walkways and bicycle paths. In Europe these walkways or bicycle paths are demarcated using a reddish colour bitumen. These bitumens are freely available in emulsions in Southern Africa and Slurrybound Macadam can be constructed in colours of red, green and brown (typical as for all-weather tennis courts).



Photo 3.9: Reddish finish to demarcate a bicycle lane

3.2.3.2 (b) Texture

Children are not encouraged to play in the streets yet communities requested designers to offer a street surface with a smoother texture as playgrounds. The Slurrybound Macadam can be constructed with a relatively smooth surface and will be suitable for tennis courts or other all weather sport fields.

3.2.4 The construction process: job-creation and empowerment related aspects

Historically construction projects were used to create employment during difficult socio-economic times. The '90's were no exception in Southern African countries. The development of emerging contractors became an important discipline in the socio-economic, political and engineering fields. The financial feasibility of these programmes was analyzed by several academics and professionals, comprising engineers, sociologists and economists. Various authors have reported in favour of these programmes while others warned that even a well-intended labour-intensive construction approach would not have the desired effect (du Toit, et al 1997). This debate is healthy and must be encouraged because important indicators are so defined. A pre-investment study for a national public works programme in 1994 by Phillips et al recommended that the public section must be systematically re-orientated to provide infrastructure on a sustainable basis to increase job creating skills development and capacity building; and a fund that would support communities undertaking their own public works (Phillips et al, 1995).

The first milestone towards empowerment in the construction industry was job-creation through labour-intensive construction techniques and the development of appropriate technologies. A second milestone was when authorities introduced the principle of empowerment with the aim to deliver infrastructure and simultaneously develop emerging contractors. These programmes have been in decline over the last period 2001-2003 (Watermeyer, et al 1998) two years as the industry is busy moving to a new policy of targeted procurements which is considered the third milestone. In the broad political arena the RDP policy was transformed to the GEAR-policy which explains the change from labour-intensive construction to empowerment programmes to targeted procurement.

The Expanded Public Works Programme was launched by President Mbeki in his state of the nation address in 2003 as a short-to-medium term programme aimed at alleviating and reducing unemployment. This programme places a high premium on training and encourages construction methods where the optimum job opportunities are created through the use of an appropriate mix of labour and machines, with a preference for labour where technically and economically feasible, without compromising the quality of the product.

The initial programmes had job-creation as the main goal and the application of labour intensive construction methods was encouraged. These were not necessarily the most economical but the higher premium was discounted against the social upliftment. The next development was an intelligent mix of labour-intensive and machine-intensive activities to improve the economical performance of the projects. Several appropriate labour intensive technologies were developed i.e. the foam gravel, emulsion treated gravel and Slurrybound Macadam techniques. (Hattingh, 2003)

The empowerment programmes developed from these projects. The main features of these programmes entail the creation of an enabling contractual environment. Restrictive practices in the tendering and contracting environment are removed and technical support services are provided to the contractor. The authority had to commit itself to:

- Avail training and development projects on a sustainable basis
- Provide support services like material training and management support
- Revise procurement practices such as simplification of tender documentation, reduce or waive tender deposits, conduct tender workshops and to allow for the adjustment of inappropriate rates, to ensure adequate provision for the work under consideration
- Address the constraints in the construction environment *inter alia* sureties, retention money, public liability insurances and long payment cycles.

These programmes were extremely successful in developing skilled small contractors. However, the lack of sustainable programmes in this "enabled" environment resulted in a turnover too low for the contractors to survive in the construction industry. Only a limited number are still active in the industry.

A protected or enabling environment must be seen only as an entry point for SMME's into the industry. If the protection is withdrawn the SMME must be able to survive in a competitive construction environment (Hattingh, Skhosana (2001)). The re-engineering of construction technologies and the development of appropriate technologies must be encouraged. (Hattingh et al 2007).

In formulating an empowerment philosophy several authors define the following criteria, low mechanization level, building elements which can be utilised by hand, skill levels required, sustainability and financial and economic feasibility (Horak, 2003). The Slurrybound Macadam technology has been developed to satisfy these criteria.

Mechanisation level: Direct labour can be seen as the entry point en route to empowerment. On a relative scale of empowerment, it is possible to illustrate progress of empowerment in terms of contractor development as a function of mechanisation level of the contractors (Horak,2003). Several construction techniques can be superimposed on the scale of empowerment as defined by Horak. This principle is illustrated in Table 3.2.

Table 3.2: Mechanisation level of some labour-intensive construction techniques (Horak, 2003)

3.2.4.1 Construction technique	Level of Mechanisation	3.2.4.2 Discussion
Crushed Stone / Cemented	High	▪ Machine intensive
100 – 150mm water-/ dry bound Macadam	High	• Heavy (12 ton) roller required. • Density specification to be met. • Light surfacing types (seals) not recommended.
Foam gravel bases	High	• Graded material to be compacted to specification. • Mechanical mixing often introduced.
100 – 150mm composite Macadam	Medium	Heavy (12 ton plus) roller required. Density specification to be met.
Emulsion treated bases	Medium	• Graded material to be compacted to specification. • Mechanical mixing often introduced.
Concrete Interlocking blocks	Medium	Manufacturing considered mechanised.
75mm composite Macadam	Low	Only light pedestrian rollers required. "Orientation of aggregate sufficient.
Slurry-bound Macadam	Low	Only light pedestrian rollers required. "Orientation" of aggregate sufficient.
Direct labour	Entry point	Entry point

The Slurrybound Macadam can be plotted at the entry-level due to its low mechanization level.

The total cost to equip a team of say 10 workers is set out below (2011 rand value).

- High frequency plate vibrator compactors
  2 @ R17,500.00 ..... R 35,000.00
- Concrete mixer (optional) ..... R 100,000.00
- Spinning beam unit ..... R 50,000.00
- Consumables
  (squeezes, wheelbarrows, guide rails, safety gear, etc.) ..... R 15,000.00

R 200,000.00

With a capital layout of R200,000 a team can be equipped to produce a surfacing type equivalent to an asphalt requiring a small mobile batching plant valued at R6 million.



Photo 3.10: Slurrybound Macadam team with all their equipment

Level of accessibility to the technology: The human friendliness of the technology is a measure of access to plant, production rates and potential profitability. The level of accessibility to the technology includes access to plant and equipment, potential production rates and potential profit.

The equipment necessary to apply the Slurrrybound Macadam technique is readily available all over the world at very low costs. The exception is the motorized spinning beam which was modified and patented through this research work. However, the technology can be applied without this piece of equipment if it is substituted with a walk-behind drum roller and static straight-edge. All the equipment necessary to construct a Slurrybound Macadam can be fitted on a 3-ton flatbed truck. Establishment is thus relatively easy and consequently less costly.

The labour component of the Slurrybound Macadam accounts for between 20 – 30% of the total costs of the product (Materials, labour, equipment overheads etc). The workforce can therefore easily earn a living wage at decent production rates without escalating the costs of the product.

Any technology where the labour-component is less than 15% will require either mechanical intervention or very high production rates to ensure a living wage for the workforce for the product to remain a cost competitive alternative. This is normally not sustainable and will either result in exploitation of the workforce or inflated cost of the product.

Sustainability: Although the road authorities are held accountable for sustainable labour-intensive and/or empowerment programmes the technologies must also have application potential on a wider front. This will only happen if the technology offers cost-effective and high quality solutions to the clients requirements. An example is the wide application of interlocking concrete blocks in private sector development projects. The Slurrybound Macadam technology offers high quality cost efficient solutions to the market and will generate sustainable opportunities.

Financial and economic feasibility: The financial feasibility of labour-intensive construction was analyzed by several academics and professionals comprising engineers, sociologists and economists (Phillips, 1995).

Various authors have reported that labour-intensive methods can indeed be cost-effective where others warned that even a well-intended labour-intensive construction approach will not have the desired effect (du Toit & Smith, 1997). It is premature to take a position either for or against labour-intensive construction. The labour-intensive construction industry is a developing industry which will contribute substantially together with the established construction industry to alleviate unemployment.

Road and street infrastructure is primarily funded by public funds. Transparency is therefore a prerequisite and thorough socio-economic analysis must be performed to justify the recommended actions. The socio economic analysis will include:

- The percentage of the contract value that will be retained by the community
- The extent of local job creation
- The extent to which the project will serve as a vehicle for affirmative business enterprise development.

The cost structure of some labour-intensive construction techniques is shown in Table 3.3. The cost structure of a conventional crushed stone base layer has been used as reference. An envelope range for each technology is given as the cost structure may be influenced by several factors such as:

- Affordability of machinery and equipment
- Labour component
- Production rate
- Cost of materials (availability of natural materials)
- Life-cycle costs

Table 3.3: Cost structure comparison of some labour-intensive base layer construction techniques (Potgieter et al, 1997)

Construction type	**Comparative rating of total costs (Reference: G1)**	**Cost of plant and equipment (%)**	**Labour component (%)**	**Material component (%)**	**Production rate (%)**	**Dominant features**
Conventional (crushed stone layer)	1	40-45	7-12	40-45	Fast	Low labour component
Water-bound Macadam	1-1,10	35-45	20-30	20-30	Medium	High plant costs
Slurry-bound Macadam	1-1,20	25-30	25-35	30-40	Medium	Low equipment costs
Composite Macadam	0,9-1,20	40-45	10-15	35-45	Fast	Low equipment & material costs
Foam gravel	0,9-1,20	40-45	10-15	35-45	Fast	Fast construction
Emulsion treated bases	0,7-1,20	30-40	30-35	20-30	Slow	Low material costs
Concrete interlocking blocks	1,1-1,20	40-45	10-15	35-45	Fast	High manufacturing costs

The Slurrybound Macadam technology is a good example of an empowerment-friendly technology. The defined criteria are optimally satisfied.

If we do the same comparison on surfacing technologies with conventional asphalt, as reference, the results will be as shown in Table 3.4.

Table 3.4: Cost structure comparison of some labour-intensive surfacing techniques

Surfacing type	Comparative rating of total costs relative rating of total costs (Reference Hot Asphalt)	Cost of plant and equipment	Labour component (%)	Material component (%)	Production rate (%)	Dominant features
Conventional asphalt	1	40-45	7-10	40-45	Fast	Low labour component
Single seal 'Chippy'-techniques	0.3	25-30	14-16	40-45	Fast	Limited technical applications (low traffic)
Cape seal	0.5	30-40	16-18	40-45	Medium	Medium labour component (medium traffic)
Slurrybound Macadam	1	25-30	20-35	30-40	Medium	Low equipment – wide application range
Concrete interlocking blocks	1.5	40-45	10-15		Fast	Over supply in structural strength

The relative low costs and high labour component will make the Slurrybound Macadam an ideal surface to specify. From a structural perspective the thickness of the Slurrybound Macadam can be varied from 15mm to 50mm which makes it suitable for use from low to very high traffic volumes.

3.3 The Construction Equipment

Equipment necessary to construct a Slurrybound Macadam surface layer is grouped together below in terms of its function in the construction process, namely:

- Placing
- Levelling
- Mixing
- Compaction / penetration
- Trimming / finishing

Unlike other Macadam base technologies all these activities can be done using light easy to manoeuvre equipment at a very low mechanization level.

3.3.1 Placing

The basic equipment necessary to place the various components of a SM-surface are wheelbarrows, ballast-forks, rakes and spades. The coarse aggregates framework in the SM-structure is normally formed by spreading at least three stones on top of each other. The targeted application rate of the stone is not nearly as difficult to achieve as, for example, for bituminous stone seals where very strict tolerances will apply. The equipment is therefore rudimentary, cheap and easy to obtain. Development by others in the field of labour-intensive construction must be mentioned. The art of chip spreading, within strict tolerances, by using labour-intensive means, has received a Sabita award (2005) for excellence in engineering. Chippy, a labour-intensive chip spreader, was developed and patented by Tarfix (Pty) Ltd.



Photo 3.11: 'Chippy' a labour-intensive chip spreader

Placing the aggregate of SMB-surface layers of thickness less than 36mm can be greatly improved using Chippy. This is however, not necessary for the successful placing of the coarse aggregate and does not need to be specified. With reference to team balancing a team of 10 workers needs to be equipped with two wheelbarrows, four ballast forks and four rakes. Production will be greatly enhanced if stones can be delivered on the road at the required spacing.

3.3.2 Levelling

The basic equipment necessary to level and trim the loose aggregate are guide rails and a straight-edge. The guide rail is used to iron out all undulations and level problems in the layer to be surfaced. It must therefore be rigid and have sufficient dimensions not to bend or shift. Preferably the guide rail must be nailed to the surface to be overlaid. During slurry-penetrations the slurry tends to lift the guide rail if it is not thoroughly secured to the base. The height of the guide rail must be selected to ensure that the minimum layer thickness is achieved across the road. The height is not necessarily equivalent to the layer thickness of the SM-layer because allowance must be made for cambered cross-sections or surface undulations.

The straight-edge is the most important piece of equipment required to ensure finishing within tolerances. The straight-edge forms a template in combination with the guardrail. The 'template' must be trial fitted at all the stages during the construction process.

The straight-edge profiles are selected such that it is easy to manoeuvre. Streets were constructed where the straight edge was used like the blade of a motor grader. Pull-bars were attached to the straight-edge and workers were requested to pull the straight-edge sliding along the guide rails.

This exercise was not really successful as only one pass was possible. During a second-pass the stones would be disturbed by the feet of the pulling workers.



Photo 3.12: Straight-edge pulled by workers (Victoria West)

The straight-edge must not be used as a levelling beam but merely as a template. The straight-edge was further improved by replacing the solid beam with a trellice. Stone could then be added to the layer through the open-trellice work.

Experience has proved that overfilling during placing is a more common mistake than short filling. The trellice type straight-edge was therefore not really used. Surplus stones have to be removed by ballast-forks and wheelbarrows.

During 2003 with the construction of the concrete-inlays on the N3 the use of a spinning beam and vibrating straight-edge was witnessed. The author involved the contractor to make this equipment available for use on the SM-technology.



Photo 3.13: Spinning beam used with concrete inlays on the N3

The spinning beam can be described as a spinning straight edge leveller comprising a cylindrical member rotatable about a central axis which is pulled along a guide rail so as to provide dynamic compaction of the layer. The cylindrical member is caused to rotate by means of an engine and is pulled in the opposite direction to which the cylindrical member rotates.

The first set (spinning beam and vibratory straight edge) was used in Hoale Street in Soweto on SM-trial sections (2002). As a motorized straight-edge the spinning beam shows great potential for further modification.

The vibratory straight edge was not really a success because unlike concrete the SM-layer is not premixed and the coarse stone and bituminous slurry have to be placed in separate activities. Further research has proved that the stone-interlock is not achieved if all the aggregate (slurry and coarse stone) is premixed especially for the thicker layers. Sufficient penetration was not achieved by the use of the vibratory straight edge without the plate vibratory compaction.

3.3.3 Mixing

The mixing of the bituminous slurry can be done either manually or by using small concrete mixers (1m^3 capacity).

Thorough planning and team-balancing principles must be applied to decide whether mixing will be done by hand or using motorized concrete mixers. Normally it is a function of availability and costs of labour and the scope of the work.

Obviously, hand mixing will require more experienced and reliable supervision to ensure that quality is not compromised. However, it is relative easy to obtain a mix within the specified consistency. If the scope of the project is bigger the employment of motorized concrete mixers may be warranted.



Photo 3.14: Slurry mixing by hand

3.3.4 Compaction / penetration

The required densification level of a Slurrybound Macadam layer is less than the required densification level of a Waterbound Macadam layer.

This is due to the fact that the filler material (bituminous slurry) in the case of Slurrybound Macadam has superior properties than the filler material (sand) used in Waterbound Macadams.

Four densifications levels were defined by Hattingh and Potgieter (1999) namely loose, orientated, interlocked and densified.

The "loose" densification level is achieved when the aggregate is levelled out using rakes and ballast forks. The "orientation" densification level is achieved if the loose material is compacted by means of a light plate vibratory compactor. The aggregate is considered "interlocked" if heavy equipment (12 ton) roller compaction is applied. No movement of the aggregate is visible when the heavy roller passes over the skeleton. Densification is achieved when the pavement is subjected to considerable traffic loading.

The four levels are presented in Figure 2.3.

With both Slurrybound Macadams and Waterbound Macadams the filler material is applied after "orientation" stage. In the case of the Waterbound Macadam heavy rollers are required to achieve interlock whilst the compaction effort for Slurrybound Macadam requires only the plate vibratory compactors. The addition of the bituminous emulsion in the case of Slurrybound Macadam resulted in easier flow and penetration of the filler material. Unlike Waterbound Macadam a Slurrybound Macadam is not densified to interlock density. The degree of penetration of the slurry will determine to a great extent the ultimate density of the SM layer.

The pedestrian drum rollers (800kg) offer a multiple function in that it provides sufficient compaction energy to achieve orientation of the framework-aggregate, penetration of the slurry and a smooth polished finish of the slurry. This is essential equipment to use if the motorized spinning beam is not used. The disadvantage of a pedestrian drum roller is its limited widths creating longitudinal tramlines in the wet-slurry.

Plate vibratory compactors have been used with great success to sufficiently orientate the loose stone aggregate. The plate vibratory compactors are the preferred equipment to achieve penetration of the slurry through the stone matrix. High frequency plate vibratory compactors ; with specified frequency of 4000-6000 vibrations per minute (Wacker, 2006) give the best results. As for the pedestrian drum rollers the limited widths of the equipment also create unsightly tramlines, costly to camouflage or remove.

3.3.5 Penetration of the slurry

The penetration of the slurry is mainly governed by the following factors, namely:

- Consistency of the slurry
- The voids in the stone matrix
- The type of equipment
- The thickness of the layer

Consistency of the slurry: The CPA/C1-method for the determination of the consistency of unmodified slow settling bituminous slurry mixes was used. The following modification was introduced to the standard equipment. The flat metal plate was replaced by a plastic laminated paper sheet, which could be destroyed after a number of uses. The slurry mix was placed in the standard flow cone on a flat surface on the laminated flow sheet. The slurry mix is allowed to flow over the circles until the flow stops. After several experiments a flow between 60mm and 70mm was found to present the optimum consistency for penetration. This was done with the construction of Molo Street in Zola, Soweto. A flow between 30 and 40mm is recommended for construction of a Cape Seal (University of Pretoria, n.d.). Obviously the aggregate type and source will bare a significant influence on the required flow. This needs to be calibrated for each slurry mix.

The consistency (flow) of a slurry mix suitable for Slurrybound Macadam construction is thus much higher than the flow for Cape Seal construction.

The voids in the stone mix are a function of the shape of the coarse aggregate (governed by flakiness specifications), the cleanliness of the aggregate and the degree of orientation (densification) of the coarse aggregate. Single-sized aggregate complying with the specifications of a road stone (COLTO spec) is required. This cannot be relaxed if the final product needs to conform to the specified Marshall-criteria. Streets were constructed where chrome-slag was used (CMR-Lydenburg) but the final product specification was relaxed for reasons of cost and low traffic volumes. These streets were constructed in 1998 and during a recent inspection it was noted that they still perform satisfactorily.

High frequency compactors are recommended to achieve satisfactory penetration of the slurry. The thickness of the layer is not a limiting factor in terms of penetration but rather in terms of economics. If the correct stone size is used layer thicknesses of up to 150mm can be constructed using the slurrybound technology (Busbays in Mohlakeng, 1995). However, the economic cost range of a Slurrybound Macadam thickness is between 15mm and 50mm thick.

3.3.6 Trimming / finishing

Once all the above principles were correctly applied the surface layer will be dense, free of irregularities and undulations and ready for the final trimming or finishing. Several experimental finishing techniques were applied with a varying degree of success. The most cost efficient method is to use a wet-burlap dragged across the wet slurry. It is recommended that the burlap is not dragged in a longitudinal direction due to difficulty to keep the draglines parallel. Using the wet burlap technique will not improve surface irregularities.



Photo 3.15: Wet burlap finishing



Photo 3.16: Spinning beam finishing

A second finishing technique is to apply a final slurry layer using the spinning beam. The guide rails remain in-place and are also used in their original position during this stage of construction. Alternatively flat bars may be placed on the completed layer to act as guide rails for the spinning beam. The wet slurry is continuously

spread in front of the spinning beam which is dragged against the direction of rotation. The gap between the guide rail and the spinning beam across the road surface is filled with slurry whilst the spinning beam polishes the final layer. A surface free of any irregularities is achieved using this technique. The results on Molo Street in Soweto are given below.

A 3m straight edge was placed over the full length of the street and irregularities were measured using a calibrated wedge. In addition the straight edge was placed across the road at 3m intervals and the maximum irregularities were measured. The complete results are given below.

Table 3.5: Deviations before final slurry – Molo Street, Soweto

Position (m)	Deviation (mm)		Position (m)	Deviation (mm)	
	Long section	Cross section		Long section	Cross section
CH: 0	3.5	4	102	6	0
3	5	9	105	4.5	3
6	3	4	108	2	0
9	3.5	5	111	1	1
12	8	2.5	114	0	0
15	2	2.5	117	0	0
18	2	5	120	2.5	0
21	2	2	123	0	0
24	1	2	126	0	0
27	4	8.5	129	3.5	3.5
30	2	0	132	0	0
33	2.5	3	135	0	0
36	0	1	138	1	0
39	1	3.5	141	1	0
42	3.5	2	144	4.5	0
45	5	4.5	147	0	0
48	4	5	150	1.5	1
51	0	0	153	0	0
54	2	0	156	0	0
57	2	0	159	0	0
60	0	2.5	162	1.5	2
63	5.5	5	165	2	0.5
66	7	2	168	3	1.5
69	0	0	171	0	2
72	1	2	174	0	0
75	0	0	177	0	0
78	1	2	180	2.5	0
81	0	0	183	0	0
84	1	2.5	186	1	0.5
87	0	0	189	3.5	2
90	0	0	192	2	0
93	0	4	195	0	0
96	1	1	198	3	0.5
99	1	1	201	3	1

Table 3.6: Deviations after final slurry - Molo Street, Soweto

Position (m)	Deviation (mm)		Position (m)	Deviation (mm)	
	Long section	Cross section		Long section	Cross section
CH: 0	1	3	75	1	3
3	2.5	5.5	78	2	2.5
6	1.5	1	81	2	0
9	2	3	84	1	2
12	3.5	3	87	0	0
15	1.5	1	90	0	0
18	2	2.5	93	1	0
21	2	1	96	1	0
24	0	1	99	3.5	4
27	0	2.5	102	0	3
30	2.5	3	105	3.5	2
33	0	1	108	2	0
36	1	1	111	1	0
39	0	2.5	114	0	1
42	2	2.5	117	0	0
45	3	3.5	120	0	0
48	2	1	123	2	2.5
51	1	2	126	2	1
54	3	3.5	129	2.5	0
57	3	2.5	132	0	1
60	4	3	135	2	2
63	3	2.5	138	3.5	3
66	3	3	141	1	1
69	2.5	2	144	0	1
72	0	3			

These results are evidence that a labour-intensive technique can be applied within tolerances specified for paver laid hot-mix asphaltic surfaces.



Photo 3.17: Completed Molo Street in Soweto

All the above finishing techniques were applied on full-scale projects.

The moisture variation in any finished slurry product tends to leave colour variances or stains on the surface which do not compare favourably with a fresh hot-mix asphalt. Within time and traffic these stains will disappear and the surface will have a uniform black colour. Some clients and communities find this explanation difficult to believe and other finishing techniques may be considered, namely the application of a pre-coated gritt on the fresh slurry.

The gritt consists of a 4.75mm or 6.7mm single sized stone. This work was not yet done in full-scale applications but limited to laboratory work. A diluted emulsion fog spray may also be applied to achieve a uniform fresh black colour. A further option will be to apply a bituminous single seal which will have the added advantage of an improved texture with reference to reduction of vehicular mist spray in wet conditions and improved skid resistance. This will only be considered for higher order roads.

3.4 Production Rates

The optimum composition of a Slurrybound Macadam construction team per set of equipment has been found to consist of 15 workers under one team leader, who will complete 30m³ Slurrybound Macadam per day.

A daily programme showing the basic activities are shown in Table 3.7, whilst the targeted production rates are shown in Table 3.8.

Table 3.7 Typical day of SM team

Time		Labour	Labourers
Start	**End**	**Team 1 (5)**	**Team 2 (10)**
08:00 AM	08:30 AM	Setup	Placing and leveling
08:30 AM	09:00 AM		
09:00 AM	09:30 AM		
09:30 AM	10:00 AM		
10:00 AM	10:30 AM	Plate vibrate	
10:30 AM	11:00 AM		Mix Slurry
11:00 AM	11:30 AM		
11:30 AM	12:00 PM		
12:00 PM	12:30 PM		
12:30 PM	01:00 PM		
01:00 PM	01:30 PM		Spread Slurry
01:30 PM	02:00 PM		
02:00 PM	02:30 PM	Penetration	
02:30 PM	03:00 PM		Mix Final Slurry
03:00 PM	03:30 PM		
03:30 PM	04:00 PM		
04:00 PM	04:30 PM	Trimming and finishing	
04:30 PM	05:00 PM		

Table 3.8 Targeted production rates for SM team

Work item	Time (hours)	Labourers (no)	Production unit	Production Rate (unit/man-hour)*	Total Production (unit)	Production required for (100m road, 6m wide, 50mm thickness)
Setup Guide Rail	0.5	5	-	-	-	-
Placing and Levelling	2.5	10	m3	1.2	30	30
Plate Vibratory Orientation	2	5	m2	78	780	600
Mixing Slurry	2.5	10	m3	0.55	13.75	12
Spreading Slurry	1.5	10	m3	1.5	22.5	12
Penetration	2	5	m2	78	780	600
Mixing final	1	10	m3	0.55	5.5	3
Trimming and Finishing	1	10	m2	78	780	600

*Typical production rates from experience

Compares favourable with CIDB guide to best practice: Labour-based methods and technologies for employment intensive construction works (CIDB Manual, 2010)

4 DEVELOPMENT OF LABORATORY TEST METHODS FOR SLURRYBOUND MACADAM SURFACING

4.1 Current status of Macadam Testing

The second focus point of this research was to refine laboratory test methods to an extent that Slurrybound Macadam could be designed, specified and tested to the same standard as hot-mix asphalt mixes laid by mechanical pavers.

Laboratory test methods for Macadam layers have been well researched and well documented. The introduction of the composite and Slurrybound Macadam technique resulted in some revisions in the test methods, but the testing philosophy remains basically associated with the layer works (not surfacing).

The revisions to the testing criteria were introduced following a research programme into the materials requirements and structural design aspects of Macadam pavements by the University of Pretoria. This was published in a sponsored design manual by the University of Pretoria in association with TOSAS and Potgieter Hattingh and Raspi Inc (University of Pretoria, approximate date 1998).

Although the Slurrybound Macadam technique was covered in the manual the test methods could be considered rather a mixture of layer technology and seal technology i.e. the slurry was designed and tested separately and the stone matrix was tested separately. No design and strength parameters for the layer as a whole have been determined.

However, the performance of these layers on the network was so satisfactory in terms of its structural integrity that the technology could be elevated to surface applications similar to hot-mix asphalt surfacing. With this research work the evaluation of Slurrybound Macadam in terms of the Marshall-criteria has been done. The Marshall test regime is accepted worldwide as the basic testing criteria for asphaltic materials.

4.2 Preparation of the Samples

The preparation of Marshall-briquettes using the SM technique was one of the major challenges during this research work. The challenges are namely:

- Densification of the Marshall-briquette without disturbing the stone skeleton of the briquette.
- The use of a cold-bitumen emulsion in the preparation of the briquettes. In its liquid-stage the standard Marshall compaction effort cannot be applied because the emulsion will "splat" all-over.
- Densify the briquettes to a void content similar to void content tested on cores taken from the road.

For ease of reference, the standard Marshall briquette preparation - TMH1 Method C2 (CSRA, 1986) has been summarized below.

After mixing the aggregate and binder at mixing temperatures (viscosity of the binder would determine the mixing temperature) the mix is placed in the mould and densified using 75 blows per side. Once cooled down the briquette is stripped from the mould and ready for further testing.

The preparation of the Marshall-briquette along slurrybound techniques was developed using three different phases, namely to analyze a SM-core from the road, premix all the ingredients to the same proportions and densify in a Marshall-mould using asphalt methods to prepare the briquette and finally to follow SM-techniques to prepare the Marshall briquette.

4.2.1 Phase 1: Analyze SM-core from the road

The first step was to recover samples of a Slurrybound Macadam surface from the road for laboratory testing. The binder content, gradation, densities, % voids in the mix and densities was determined in the laboratory. The test results are given in Table 4.1. The core thickness was also recorded.

Table 4.1: Marshall analysis on cores from the road

Project: Soweto	**Ring Road Doornkop**				
Sample number	**1**	**2**	**3**	**4**	**5**
Date	2003-09-30				
Binder content (%)	4.2	3.3	3.9	3.7	3.5
Sieve analysis					
26.0mm	100	100	100	100	100
19.0mm	99	100	99	100	100
13.2mm	74	59	68	74	70
9.5mm	51	47	56	50	48
6.7mm	48	44	54	42	43
4.75mm	47	43	52	41	42
2.36mm	33	30	34	31	31
1.18mm	22	21	23	22	21
0.600mm	15	15	16	16	15
0.300mm	11	11	11	11	11
0.150mm	9	8	9	9	8
0.75mm	7	6.7	7	7	6.4
Density (kg/m^3)	2447	2490	2466	2475	2497
Rice R.D	2.695	2.746	2.722	2.736	2.738
Voids in mix (%)	9.2	9.3	9.4	9.5	8.8
Core thickness (mm)	31	29.9	29.5	23.4	27

Sample number	**6**	**7**	**8**	**Average**
Date	2003-09-30			
Binder content (%)	4.3	4.3	4.3	
Sieve analysis				
26.0mm	100	100	100	100
19.0mm	100	99	98	100
13.2mm	75	76	66	70
9.5mm	57	56	51	52
6.7mm	54	53	50	48.5
4.75mm	53	52	48	46
2.36mm	36	36	31	32.8
1.18mm	25	24	20	22.3
0.600mm	18	17	13	15.6
0.300mm	13	12	10	11.3
0.150mm	10	9	7	8.6
0.75mm	8	7.3	5.9	6.9
Density (kg/m^3)	2442	2465	2454	
Rice R.D	2.702	2.694	2.703	
Voids in mix (%)	9.6	8.5	9.2	
Core thickness (mm)	26.3	27.6	31.8	

4.2.2 Phase 2: Prepare Marshall briquette using asphalt methods

Materials (stone and filler sand) from the same sources were obtained and mixed together to the same grading as the cores. The binder content was also determined and Marshall briquettes were prepared accordingly. The aggregate, filler sand and binder were mixed together in a briquette, the emulsion was allowed to break, the briquette was preheated to 150°C and then densified at 138°C using respectively, 30, 35 and 40 blows per side.

The briquettes were then tested in accordance with the Marshall criteria. The results have been summarised in Table 4.2.

Table 4.2: Marshall test results of SM in comparison with hot-mix asphalt specifications

Asphalt Type	**AC (med. Cont.)**	**BTB**	**Slurrybound Macadam**
Nominal binder content (%)	5.5	4.5	4
Voids in Mix (%)	3 – 6	3 – 6	6
Stab. Marshall (kN) (E4 Traffic)	8 – 18	8 – 18	14.8
Flow (mm)	2 – 4	2 – 4	4
Stab/Flow Ratio (minimum)	2.5	2.5	3.7
ITS (kPa)	800	800	859
Film Thickness (µm)	5	5	7.1

4.2.3 Phase 3: Prepare SM-core in the laboratory

The % voids in the mix of the SM-briquette prepared using the conventional method was on the upper limit of the void specifications for asphalt mixes, but approximately 3% lower than the voids determined from the cores recovered from the road. All the other Marshall specifications were met.

19,0mm single sized crushed stone was used as coarse aggregate. The nominal slurry was mixed using a crusher-dust, 240 ℓ/m³ of 60% anionic bitumen emulsion and 1% of 42,5 CEM III cement. Several experiments were then conducted in an effort to prepare a SM-briquette along Marshall principles as follows:

<u>Experiment 1:</u> *Aggregate and slurry in layers densified using 30 Marshall blows per side.*

The mould was packed with aggregate and slurry in layers. A first layer aggregate was packed followed by a layer slurry. The slurry was allowed to break before the next layer aggregate was packed. Four layers aggregate was packed. The mould was heated to 138°C and compacted using 30 Marshall-blows per side.



Photo 4.1: Experiment 1: 1st layer aggregate



Photo 4.3: Experiment 1: Briquette after early stripping



Photo 4.2: Experiment 1: 2nd layer aggregate



Photo 4.4: Experiment 1: Indication of slurry penetration

The stone skeleton does not truly simulate the field stone orientation. The slurry is placed between the stones which is also a poor simulation of the construction process.

<u>Experiment 2:</u> *Aggregate slurry in four layers compacted using 35 Marshall blows per side.*

The mould was prepared as for experiment 1, but densified using 35 Marshall - blows per side.

As for experiment 1 the stone skeleton may not be representative of the field orientation.

Experiment 3: *Aggregate and slurry in four layers densified using 38 Marshall-blows per side.*

The mould was prepared as for experiment 1, but densified using 38 Marshall-blows per side. The stone skeleton and slurry penetration is not a true simulation of the field technique.

Experiment 4: *Aggregate and slurry in layer of 32mm using 38 Marshall-blows per side*

The mould was filled with 19,0mm aggregate to 32,0mm, and the slurry was added on top. After breaking of the emulsion the sample was heated to 138°C and compacted using 38 blows per side.

Although the field conditions are better simulated the slurry penetration was insufficient to present a briquette. The briquette disintegrated when the mould was removed.



Photo 4.5: Experiment 4: Insufficient slurry penetration

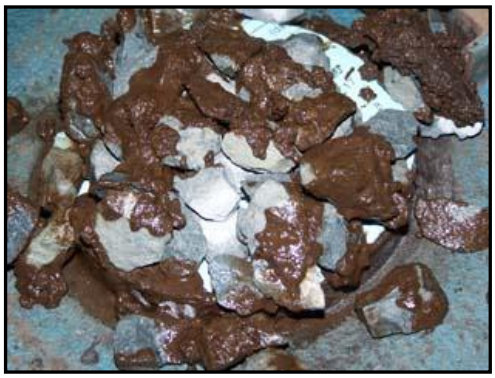


Photo 4.6: Experiment 4: Briquette disintegrated

Experiment 5: *Aggregate and slurry in layers densified using 30 Marshall blows per side with no heating of the sample.*

The mould was prepared as for experiment 1 densified at 30 Marshall blows per side at ambient temperature. The briquette also disintegrated when the mould was removed.

Experiment 6: *Aggregate and slurry in layers densified using 38 Marshall-blows per side with heating of the aggregate 138°C after each successive layer.*

As for experiment 1 but the briquette was heated after each layer.

The void content of briquettes 1, 2, 3 and 6 was determined using the Marshall method. The results are presented in Table 4.3.

Table 4.3: Void content of experimental SM Marshall briquettes

Experiment	Treatment summary	Heated °C	No blows per side	Voids
1	4-Layer aggregate 4-Layer slurry	138°	30	11,6
2	4-Layer aggregate 4-Layer slurry	138°	35	10,5
3	4-Layer aggregate 4-Layer slurry	138°	38	10,1
4	1-Layer to 32 mm	138°	38	Slurry did not penetrate
5	4-Layer aggregate 4-Layer slurry	Ambient	30	Slurry does not stick to aggregate
6	4-Layer aggregate 4-Layer slurry	Heating per layer 138°C	32	13,1

The outcome of experiments 1 to 6 were not satisfactory in that the main challenges,

- Not to disturb the stone skeleton
- To use cold bituminous emulsion

were not overcome. However, the void contents of the briquettes (1, 2, 3 and 6) were similar to the voids tested on the core samples from the road.

Experiment 7 (final): *Densification of SM-briquette simulates construction technique*

In the field, the penetration of the slurry into the voids is done using vibratory equipment. Instead of Marshall hammer blows the vibrating principle was introduced in the laboratory. The Marshall mould was mounted to a vibratory table and the Marshall hammer placed as a loose surcharge weight on the coarse aggregate. The outcome of this experiment was satisfactory in that all challenges were overcome. The complete procedures are explained below:

- Mount a Proctor-mould to a vibratory table.
- Fill the mould with the coarse aggregate to half 32mm.
- Place the Marshall hammer as loose weight on the coarse aggregate and vibrate (using the table) for 60 seconds.
- Wet the aggregate using either water or a bitumen-emulsion[1].
- Mix the slurry to specified consistency using the flow plate[2].
- Place the determined[3] volume slurry on top of the coarse aggregate with the Marshall hammer as loose weight on top and allow the table to vibrate for 60 seconds.
- Repeat the above to achieve 60mm briquette thickness.
- Cure the briquette in the mould before stripping.
- Briquettes ready for further Marshall tests.

[1] Deduct volume used from optimum emulsion content.

[2] Optimum slurry mix and consistency is a separate exercise.

[3] Determined in terms of volumetric principles through experimentation.



Photo 4.7: Experiment 7: Surcharge weight



Photo 4.8: Experiment 7: Briquette after early stripping showing excellent slurry penetration

4.3 Marshall tests on SM Briquettes

Finally, all the challenges were overcome and procedures determined to prepare Marshall-briquettes on Slurrybound Macadam principles.

Initial Marshall tests conducted on the SM-briquettes are shown in Table 4.4.

Table 4.4: Marshall test results on SM-briquettes

	Cores from road				Premix briquettes (CPA method)			Slurrybound briquettes		
Binder content	4.2	3.3	3.9	3.7	3.5	4	4.5	*	*	*
Voids in mix (%)	9.2	9.3	9.4	9.5	6.9	6.0	5.2	8.2	9.9	8.6
Thickness (mm)	31.0	29.9	29.5	23.4						
Stab (kN)					14.4	14.8	14.6		13.1	14.3
Flow (mm)					3.1	4.0	3.3		4.6	5.1
Stab / Flow Ratio					4.7	3.7	4.5		2.9	2.8
ITS (kPa)					841	859	801			
Immersion Index									74.5	
Dynamic Creep (mPa)									22.1	
Film thickness					6.2	7.1	8.0			

Although the statistical sample is still relatively small these initial results confirm that the performance of a SM is within the specification range of coarse graded hot-mix asphalts. High stability (kN) and dynamic creep values have been recorded. The voids tested on the modified briquette are similar to the voids of cores sampled from the road. The laboratory results will thus be a true reflection of the performance of the SM surface. An extended testing programme is planned as a further phase to the research work. The SM technology must now be exposed to the established asphalt technology testing series i.e. different stone sizes, binder types, binder content and load accelerated testing.

The Slurrybound Macadam construction technique can now be researched as an asphalt technology.

5 CONCLUSION

This research work was done during the construction of over 400km Macadam roads constructed along labour-intensive principles. Various construction techniques were followed with different degrees of success. These construction techniques are now well documented and assessed holistically from different viewpoints.

The thickness of the Slurrybound Macadam layer was gradually reduced from a 125mm thick layer to a 15mm thick layer, or in other words from a base layer thickness to appropriate surfacing thickness. The stricter construction tolerances associated with surfacing technologies had to be achieved with construction processes which satisfied the required goals from a structural, functional, aesthetical, job creation and empowerment viewpoint.

Construction equipment and techniques were developed to enable construction of high quality labour-intensive surfacing in accordance with specifications equivalent to hot mix paver laid asphalts. The Slurrybound Macadam can be batched using plant not exceeding R200,000 in comparison with a mobile hot mix asphalt batching plants valued at almost R6 million, whilst the labour component will increase threefold per unit of expenditure without increasing the basic product costs.

Preparation procedures of Marshall briquettes on complete Slurrybound Macadam principles have been developed. This entails that the coarse aggregate framework forms part of the Marshall briquette and the briquette is prepared using a bituminous emulsion and not a substitute penetration grade bitumen. Previously, briquettes were prepared using a penetration grade bitumen to substitute the bituminous emulsion without the coarse aggregate framework.

Preliminary Marshall tests were done on the Slurrybound Macadam briquettes. The Slurrybound Macadam can now be researched, designed, specified and tested to the same standard as hot mix asphalts.

A specification in COLTO format has been drafted accordingly, as part of this research project.

6. EXTENDED RESEARCH REQUIRED

Further research work is necessary to establish a better understanding of the design parameters when a Slurrybound Macadam is designed as a surfacing layer. This will entail analysis of the following:

Contribution of aggregate frame structure against properties of the filler material using Marshall Criteria. The properties of the filler material will be mainly governed by the binder type, binder modification and binder content. Whilst the influence of the aggregate frame structure will be governed by stone size and the level of densification, orientation, interlock and densification.

The standard density tests do not supply sufficient information on the degree of compaction or the compaction effort.

The extent to which the voids in the framework were filled either by sand or slurry determine the achieved densities recorded but say very little on the condition of the aggregate frame structure.

More research work needs to be done to ensure that designers specify the correct criteria and tests to ensure that the required design parameters; flexibility, rut resistance and permeability are achieved. The test methods (Marshall criteria) developed with this research may be useful for further research.

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