Best practice for the design and construction of slurry seals

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Manual 28
Best practice for the design and construction of slurry seals

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* Withdrawn and their contents have been incorporated in *Technical Guideline 1* (see below)
** Withdrawn and its software incorporated in *TRH12: Flexible pavement rehabilitation investigation and design*
***These manuals have been withdrawn and contents incorporated in *Technical Guideline 2* (see below).

Technical Guidelines

TG1	The use of modified binders in road construction
TG2	Bitumen stabilised materials
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DVDs

DVD100	Testing of bituminous products
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FOREWORD

Background

The use of slurry for road surfacing purposes dates back to the early 1950s in the USA. Although the components are similar to hot mix asphalt, the manufacturing, construction and thickness of application resulted in a different approach to the design of slurries.

Different methods of slurry design have developed in South Africa to determine the appropriate binder content for specific materials and purposes, each providing reasonable end products. However, as different test methods are applied, interpretation of the results has become difficult, requiring experience to select the best options for specific situations.

Purpose of this document

The purpose of this document is to provide practitioners with information and guidelines to select the appropriate type of slurry for specific applications and to assist in the design and construction of slurry mixes to ensure good performance.

Information and guidelines as recommended by the International Slurry Surfacing Association are incorporated into this document to highlight the difference from South African practice, but also to show where specifications could be relaxed.

Although information for selection and construction of microsurfacings is provided, the design thereof is considered highly specialised and therefore not covered to the same detail as conventional slurries.

SCOPE

Following a short background on slurry components and materials, the different types and their uses in southern Africa are discussed. This is followed by detailed discussions regarding the design of slurries and recommendations for South African practitioners. The document is concluded with guidelines on best construction practice, quality control aspects and typical problems.

1 COMPONENTS AND MATERIALS

1.1 Basic slurry types

Slurry types used in southern Africa could be divided into two groups, i.e. conventional slurry and microsurfacing (rapid setting, polymer modified slurry).

The typical application and relevant thickness for each are shown in Table 1.

Table 1: Basic slurry types and application

Conventional Slurry	Microsurfacing
Texture slurry (1 – 3 mm)	Medium overlay (6 – 8 mm)
Thin overlay (4 – 6 mm)	Thick overlay (8 – 15 mm)
Medium overlay (6 – 8 mm)	Shape correction (8 – 15 mm)
Thick overlay (8 – 12 mm)	Rut filling (8 – 30 mm)
Cape Seal	
Slurry bound macadam	

1.2 Slurry composition

Slurry is a homogeneous mixture consisting of:

- Fine aggregate (normally crusher dust), or where required to satisfy grading requirements and permitted, a blend of crusher dust and a limited percentage approved natural sand);
- Stable grade bitumen emulsion (anionic or cationic) or a polymer modified stable grade emulsion;
- Filler (usually cement or lime);
- Water;
- Additive to retard the setting rate of rapid setting slurry;
- Polymer (in case of microsurfacings).

1.2.1 Fine aggregate

The most suitable aggregates are crusher dusts but could be combined with natural sands. The required grading depends on the purpose of application.

Due to their generally rounded particles, natural sands should be used with caution, preferably with a maximum of 25% in a blend with crusher dust (also refer to notes in Section 3.2.2). As sands also contain large amounts of quartzitic particles, it would be advisable to test for stripping by using test TB 115 of the International Slurry Surfacing Association[1] or the Immersion Index Test, test method C5 of TMH1[2].

1.2.2 Fillers

Cement or lime acts as a catalyst to keep the mix consistent and to improve the flow and workability of the slurry. Cement or lime should be added to all slurries, as with most aggregates there is a tendency for diluted emulsion to segregate from the larger sized particles. This emulsion then tends to float upwards to the surface of the spread slurry.

1.2.3 Water

The addition of water is necessary in order to obtain the correct slurry consistency. As a guide 160 litres of water per cubic metre of dry aggregate should be added (approximately 70-80% of the emulsion quantity). This, however, will vary with the type of aggregate and the prevailing temperature on site. On hot days extra water will be required to obtain the correct consistency for uniform spreading.

The pH of water used for the dilution of anionic bitumen emulsion should be between 7 and 9 and for that of cationic bitumen emulsion between 4 and 7. Water with a pH value outside these limits should be checked for compatibility with the emulsion. In addition to the pH requirement, if the total dissolved solids count is greater than 500 ppm, the water should be tested for compatibility with the emulsion. Generally the water content is about 10% by mass of dry aggregate. The use of excess water should be avoided.

1.2.4 Emulsion

The following types of emulsion are used extensively in South Africa for slurry seals:

Table 2: Emulsions used for slurry in South Africa

Emulsion Type	Base Bitumen
Stable grade anionic emulsion	80/100 penetration grade
Stable grade cationic emulsion	80/100 penetration grade
Quick setting cationic emulsion	80/100 penetration grade
Quick setting modified cationic emulsion	80/100 penetration grade

2 SLURRY TYPES AND USES IN SOUTHERN AFRICA

2.1 Appropriate application

2.1.1 Maintenance

Seal damage repair

The ease of manufacturing small volumes of conventional slurry lends itself to several applications, one of which is the repair of seal damage and ravelling, which often occur at seal joints or as a result of water erosion or turning actions.

Covering geotextile patches and base repairs

Potholes and failures are either patched with granular materials, cemented materials, emulsion treated materials or asphalt (BTB mixes). The surface after patching is often covered with a medium-to-fine graded slurry to protect the granular surface or to reduce the permeability of the asphalt mix.

Photograph 1: Patches covered with slurry

Edgebreak repair

Edgebreaking occur as a result of poor shoulder support. The hand repair, using asphalt, is very expensive and time consuming and has resulted in the manufacturing of equipment to clean, prime and fill the damaged edges on low volume roads with slurry (normally rapid setting).

Alternatively, and specifically on low volume roads, the edgebreaks could be filled with emulsion treated granular material, compacted, primed and covered with a medium graded slurry.

Holding action

Although not very effective in preventing crack reflection, slurry is often applied on cracked road sections to slow down rapid deterioration until a more appropriate remedial measure could be applied. This action is considered by several road authorities as a routine maintenance action.

2.1.2 Initial seals

Slurry seals

Medium to thick slurries (8 mm-15 mm) are considered appropriate for the construction as initial seals. Sabita Manual 10[3] provides more information regarding the appropriateness for different situations.

Photograph 2: Slurry as initial seal

The principle (rule of thumb) is that the minimum application thickness should be equal to the thickness of the largest aggregate in the mix and the maximum thickness equal to three times the Average Least Dimension (ALD) of the maximum aggregate size.

Cape seals

The Cape Seal was originally developed in the Cape Province of South Africa and is still used with great success, mainly as an initial construction seal but often now also as a reseal, specifically where heavy vehicle turning actions are expected or where the maintenance capability of the responsible road authority is suspect.

The initial Cape Seal consisted of a single-sized 19,0 mm aggregate, openly spaced (see photograph 3) to allow two hand-placed applications of a fine slurry. The binder application for the coarse aggregate (19,0 mm) is split into a tack coat using either hot binder e.g. 80/100 penetration grade bitumen or bitumen emulsion and a cover spray consisting usually of a diluted emulsion. A tack coat using a bitumen rubber binder, has also been found most effective where salt damage is anticipated. The recommended application rates are determined from documented design methods[4,5] taking into account the size of the aggregate, traffic and geometry of the road.

The binder content of the slurry as originally specified by the Cape Province is considered by many practitioners to be on the high side e.g.:

- First layer – 14% emulsion by mass of the dry aggregate (60% anionic stable grade emulsion);
- Second layer – 20% by mass of dry aggregate.

The typical total slurry application is 125 m^2/m^3 with approximately 66% of the volume applied in the first layer.

Cognisance should be taken that:

- Typical traffic volumes on a large portion in the Cape Province road network varied between 500 and a 1000 vehicles per day;
- High binder content slurry provides a more durable seal. The slurry is worked into the seal by hand, resulting in the traffic being more in contact with the large aggregate than with the slurry itself.

Photograph 3: Typical spread of aggregate for a Cape Seal

Experience with Cape seals on higher volume roads in the Western Cape and elsewhere[6,7] suggested some adjustments in terms of the binder application rate for the coarse aggregate as well as for the binder content of the slurry mix. Although not further discussed in this document, the following aspects are taken into account to improve the designs:

- Tack coat binder application rates. The Western Cape Provincial Department of Transport and Public Works[4] makes recommendations to reduce the binder due to heavy vehicle axle loads. The South African seal design guide (TRH3)[5] recommends the minimum binder content of the acceptable range for a single seal to hold the stone;
- It is generally accepted that the binder in the tack coat and binder adhering to the aggregate, as a result of the diluted emulsion cover spray, could have an influence on the performance of the slurry. Therefore, when heavy traffic is expected and/or at steep grades with slow moving heavy vehicles, the tendency is to reduce the binder e.g.:
  - Reduce the cover spray to 0,8 ℓ/m^2 and even to dilute the emulsion to 30% emulsion/70% water (of 60% emulsion).
  - Precoat the large aggregate and omit the cover spray
  - Omit the cover spray even when the large aggregate is not precoated. Although several cases have been reported where the cover spray has been omitted with success, this practice is not recommended. Particularly in summer the squeegee operation can loosen and roll chips around, leaving them proud on the surface and later becoming a risk for windscreen damage;
- Application of the slurry by hand or by spreader box. When applied by a spreader box, the slurry would normally cover the aggregate in “uneven” areas resulting in the tyres being in direct contact with the slurry, instead of the coarse aggregate. Such conditions would require a reduction in the slurry binder content and at least a lighter application (reduced binder) in the cover/fog spray, to reduce the risk of flushing. On the other hand if the slurry is hand-applied, only filling the voids between the coarse aggregate with the stones still standing proud, the slurry could have a much higher binder content without flushing (refer Figure 1).

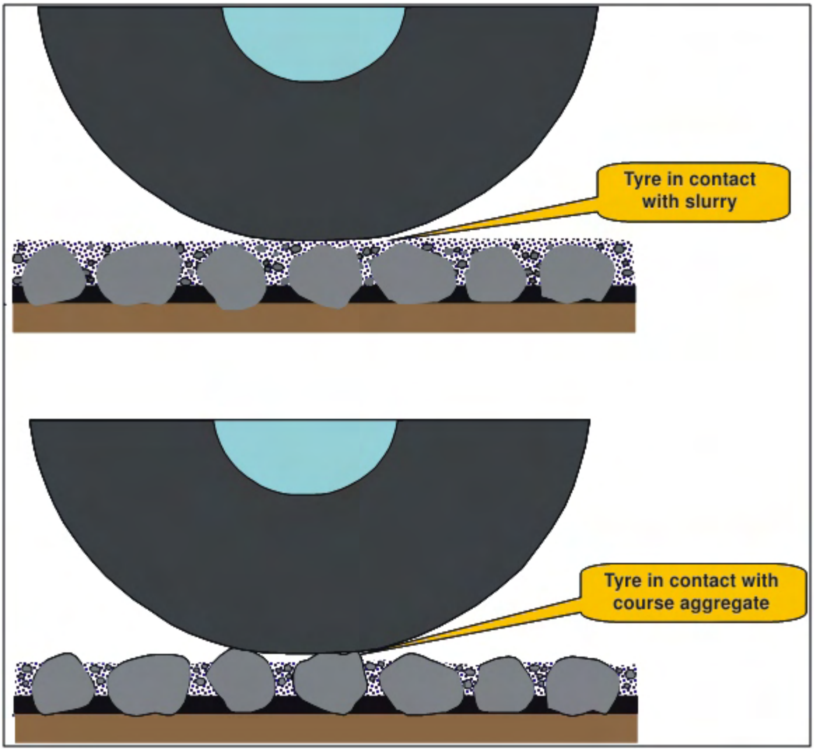


Figure 1: Tyre contact affecting design binder content

Variations on the typical Cape Seal composition include:

- Use of 13,2 mm aggregate and one layer of fine slurry;
- Use of 9,5 mm aggregate and one layer of fine slurry;
- Closely packed 19,0 mm aggregate with one layer of medium-fine or fine slurry;
- Use of 26,5 mm aggregate with two or three layers of slurry;
- Use of modified binder in the tack coat;
- Replacing conventional slurry with rapid setting slurry.

HINT

Timing before application of slurry – typically 2-4 days are required to ensure complete breaking of the emulsion used for the cover spray. However, due to influence of temperature and humidity, it is essential to visually inspect whether the water has completely evaporated from the emulsion. Four days curing is mostly specified to eliminate risks.

2.1.3 Reseals (Periodic maintenance)

Texture pre-treatment

The purpose of a texture pre-treatment is to obtain a uniform texture (medium to fine) on the existing road to allow the design and uniform transverse application of one binder application rate for a new reseal.

A texture treatment is normally required when the existing surface texture:

- Varies from fine to coarse e.g. fatty in the wheel tracks and coarse in-between;

Photograph 4: Varying existing texture

- Is coarse and the intended reseal aggregate might not be in contact with the sprayed binder.

Photograph 5: Coarse texture

NOTES

- Although TRH3[5] recommends a texture treatment when the macro texture exceeds 0,6 mm (conventional binders) or 1,0 mm (in case of modified hot binders), fitting of the intended reseal aggregate into the existing texture should be evaluated.
- Figure 2 shows the macro texture on two different seal types. Although the macro texture depth could be similar, sealing with a single seal on the first seal type, without a texture treatment, could result in aggregate loss. Resealing on the second texture with a single seal might not require any texture treatment. The effect of how the reseal aggregate fits into the existing texture is shown in Figure 3. The interpretation of texture depth measurements is well described elsewhere[8].

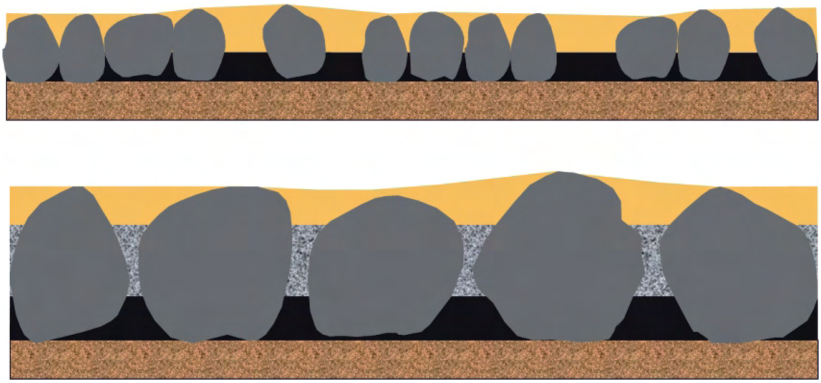


Figure 2: Macro texture

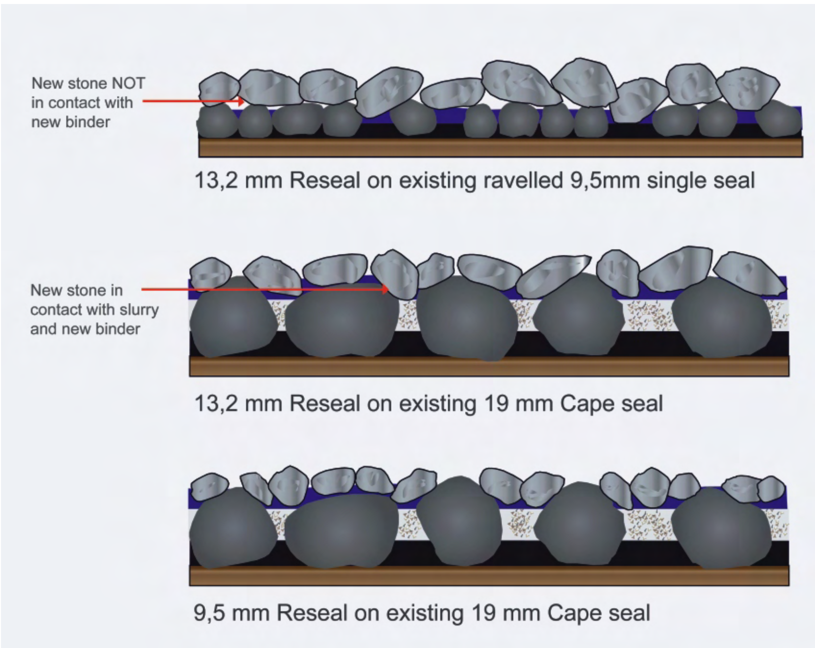


Figure 3: Resealing on different macro texture types

The fine grade, fine slurry is normally used for texture treatment by hand (refer Table 3, page 27).

Rut fill pre-treatment

Rut filling is required when the rut depth exceeds 10 mm, allowing ponding of water in the wheel tracks and the risk of aquaplaning (refer figure 4). As preventative measure, rut filling at 8 mm is recommended.

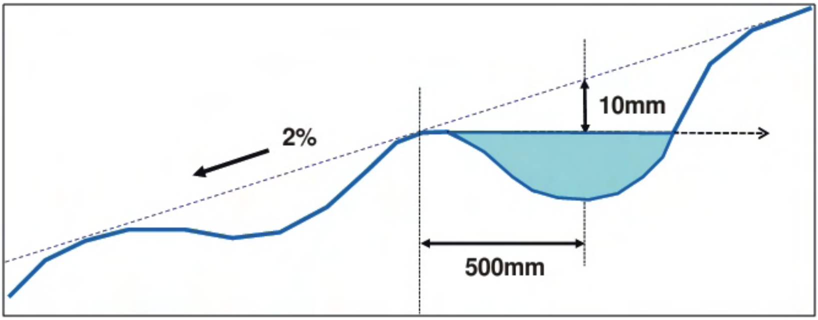


Figure 4: Ponding at 10 mm rut depth

Photograph 6: Rut filling

Filling rut depths of up to 30 mm, using rapid setting slurry and a 1 m slurry spreader box, is not uncommon in South Africa. The “before” and “after” situations are shown in photograph 2.

Overlay

Slurry overlays, with thickness between 6 mm and 15 mm, are often used as a reseal action, primarily in the municipal domain, and normally applied with a slurry spreader box and a continuous mixing slurry machine.

Photograph 7: Slurry overlay

2.2 Limitations

The most important characteristics of slurries, which are considered limitations, are:

- **Initial permeability** of especially rapid setting slurry;

> **NOTE**
>
> This limitation, however, can be overcome by insisting on pneumatic tyred compaction after placement. This requirement has been mandated by various road authorities. A trial section to verify the timing and number of passes under prevailing environmental conditions, and using the Marvil Permeability test[9] as assessment tool, are essential.

- **Rigidity** as a result of low film thickness, allowing quick reflection of existing cracks;
- **A thin slurry overlay as a new construction seal** cannot handle heavy vehicle turning or braking actions;
- **Construction of conventional slurries when the humidity is high (typically > 70%),** as problems could occur with breaking of the emulsion;
- **A longitudinal gradient limitation of 6 to 8% applies to a thin slurry overlay.** (Refer TRH 3 Table 4-3)[5];
- **Slurries are sensitive to volatiles in the existing surface to be overlaid** e.g. surfaces recently rejuvenated or enriched with diluted emulsions or proprietary products containing cutters. Bleeding (fattening) of the slurry is often experienced in such cases;
- **Slurry sealing should not be done on existing bleeding surfaces as excess binder in the existing seal will soon migrate to the top of the slurry seal** i.e. "Degree 4 or 5" as described in TMH9[10] – refer Appendix C;
- **Chip sealing too soon over slurry-filled ruts could result in severe aggregate embedment and a bleeding surface.** A curing period of 12 weeks is suggested. However, corrected ball penetration values less than 2 mm normally indicates low risk for excessive embedment.

3 DESIGN OF SLURRY

3.1 General principles

Key aspects to the design of slurry are:

- The mixture must be easily applied by hand with rubber squeegees or by mechanical spreaders i.e. the mixture will have a creamy consistency, which will allow it to flow readily into surface voids and interstices;
- The hardened product will have sufficient binder not to ravel but stable enough to carry the wheel loads without bleeding or deformation.

The addition of modifiers in microsurfacings improves the strength (initial stiffness) of the mix as well the aggregate/binder adhesion. Improvement of flexibility resulting from the addition of polymers is not noticeable in slurry seals. In general, 3% of polymer solids (by mass of bitumen) is regarded as the minimum amount of modifier to be added. This, however, should be established by the laboratory doing the mix design of the microsurfacing.

Different to hot mix asphalt where the bitumen content is expressed as a percentage of the total compacted mix, all the slurry seal calculations are based on uncompacted (loose) dry material, e.g.:

- The emulsion required is expressed as ℓ/m^3 of dry loose aggregate;
- If the binder quantity is converted to net cold bitumen, it is still expressed as a percentage of the mass of dry loose aggregate.

3.2 Aggregate

3.2.1 Aggregate crushing value (ACV)

The aggregate for conventional slurry seals should be approved angular crusher sand obtained from a parent rock having an **ACV not exceeding 30**.

3.2.2 Natural sand component

A mixture of crusher sand and approved clean natural sand could be used, provided the mixture does not contain more than **25% natural sand (**refer COLTO)[11].

The purpose of adding natural sand could either be to reduce costs, improve workability and lower water demand, or merely to obtain a well graded material within the specified grading envelope.

NOTES

The risk of blending more than 25% natural sand with the crusher sand depends largely on the angularity of the natural sand, the grading and the purpose of the slurry. The following experiences are shared:

- Dependent on the angularity, a natural sand content of up to 50% by mass of the aggregate blend could perform well if a cationic bitumen emulsion is used or an adhesion agent is added.
- 100% natural sand mixes have been used for thin texture treatments (<3 mm) and for Cape seals.
- South African sands are often rounded and single sized. Sand seals or slurry seals constructed with high percentages of these types of sand tend to ravel or disintegrate far quicker than crusher sand.

Based on these experiences, it is recommended that a detailed design is done when more than 25% natural sand in the mix is considered.

3.2.3 Grading

The approved aggregate grading per slurry type, for use in South Africa, is shown in Table 3.

Table 3: Aggregate grading for conventional slurry mixes

Sieve Size (mm)	Percentage passing sieve by mass									
	Fine Slurry						Course Slurry			
	Grade						Type 1		Type 2	
	Fine Range		Medium Range		Course Range		Range		Range	
14									100	100
10							100	100	85	100
7,1			100	100	100	100	85	100	70	90
5	100	100	85	100	70	90	70	90	60	80
2	85	100	50	90	40	65	40	65	35	55
1	60	90	35	70	25	45	20	40	20	40
0,60	42	72	22	50	19	34	15	30	15	30
0,30	23	48	15	37	15	25	10	20	10	20
0,15	10	27	7	20	7	18	6	15	6	15
0,075	4	12	4	12	2	8	4	10	4	10
Sand Equivalent [%]: 35 (min)										

NOTES

The Sand Equivalent is determined in accordance with SABS 838[12] or TMH1 Method B19[2]. The purpose of this test is to eliminate aggregate sources with detrimental fines or high clay content. The test is carried out by mixing the minus 4,75 mm aggregate component with water, allowing the aggregate component to gravitate and measuring the depth of easily displaceable fines.

Low sand equivalent mixes will be sensitive to “balling” when temperatures increase (photograph 36) and also have excessively high water demand.

NOTES

Although the ideal dust content range is considered to be between 5 and 12%, successes have been achieved with dust contents of up to 20%.

Conventional slurry mixes, with gradings outside the specified envelopes, have been constructed with success. It is recommended that such mixes are:

- Designed in a laboratory for appropriate binder type and content
- Prepared on site using a small concrete mixer
- Laid under the typical climatic conditions
- Evaluated under traffic.

The aggregate used in rapid-setting slurries should have the same basic properties as those specified for conventional slurries. The gradings of the aggregate to be used in rapid-setting slurries are given in Table 4.

Table 4:
Aggregate gradings for rapid-setting slurries and microsurfacings (ISSA A 143)[1]

Sieve Size (mm)	Type II % Passing	Type III % Passing	Stockpile Tolerance (%)
	Overlay or Rut fill (up to 12 mm)	Rut fill (more than 12 mm)	
10	100	100	
7,1	100	85 – 100	5
5	90 – 100	70 – 90	5
2	65 – 85	45 – 65	5
1	45 – 65	28 – 45	5
0,600	30 – 50	19 – 34	5
0,300	18 – 30	12 – 25	4
0,150	10 – 21	7 – 18	3
0,075	5 – 15	5 – 15	2

3.2.4 Binder/aggregate compatibility

The immersion index of briquettes made with slurry aggregate and 80/100 penetration grade bitumen, at the design net binder content for the slurry, should not be less than 75 when tested with Method C5 of TMH1[2] (refer Appendix B).

For rapid setting slurry the aggregate should be checked for compatibility with the emulsions to be used (refer Methylene Blue Test, Section 3.4.5).

3.2.5 Binder/water compatibility

Water found in nature may be unfit because of impurities, either in solution or colloidal suspension. Of particular concern is the presence of calcium and magnesium ions, which can affect the properties of the emulsion. (Refer *A basic asphalt emulsion manual*, Manual Series No 19 (MS19) March 1979)[13].

A simple field test, referred to as the "Can Test" is perhaps the most practical and quickest method of testing suspect water on site.

The "Can Test"

The emulsion must in the case of emulsion for slurry, be diluted in the ratio of one part emulsion to ten parts of the suspect water in a clean container. The diluted emulsion should be heated to 60°C and left to stand for approximately 20-30 minutes. (To prevent premature breaking, the water is added to the emulsion, not the emulsion to the water.) The diluted emulsion is then passed through a fine sieve (e.g., 600 µm) to determine if any premature breaking of the emulsion has occurred.

Should premature breaking occur during the "Can Test", the supplier should be consulted or further testing should be conducted to determine the cause and possible solutions (refer WCPA Materials Manual Vol 2 Chapter 2) [4].

3.2.6 Mineral filler

1 – 2% Portland cement or lime (by mass of dry aggregate) should be incorporated in the mixture. The main purpose of the filler is to obtain a creamy mixture that will not segregate easily.

NOTES

From experience the following additional guidelines:

- If the dust content (<0,075 mm) is less than 7% – 1,5% of filler should be added;
- If the dust content is greater than 7% – 1,0% of filler should be added;
- Several other fillers have been tested word-wide and could be used with success.

Concerns were raised by practitioners regarding the effectiveness of different cement types and specifically CEM V cements. Twenty two different cement samples were obtained from different suppliers and 1% per mass of aggregate mixed with both anionic and cationic emulsions.

The results obtained proved that all cement types, including CEM V, could work i.e. no segregation occurred.

However, the viscosity (thickness) of the mixes with different cement types varies and is also influenced by the type of emulsion. It has been observed, in general, that the purer cements "gel" better, leading to the additional testing to correlate the calcium oxide (CaO) content with an easily measureable parameter on site such as the "flow".

Some interesting conclusions drawn from this study are as follows:

- The viscosity of cationic slurries is much higher (less flow) than the anionic slurries;
- It was confirmed that in the case of anionic slurries, the "gelling" is caused by the presence of calcium ions in the cement while in the case of cationic slurries this reaction is caused by the change in pH from approximately 2 to 11;

- Although the perception was that the more pure the cement (CEM I), the higher the viscosity of the slurry (less flow), the results proved different, resulting in the conclusion that similar cement types from different suppliers could result in a different water demand;
- The water demand for specific purposes should be determined using the cement on site. Any change in type and/or source of cement would require re-evaluation.

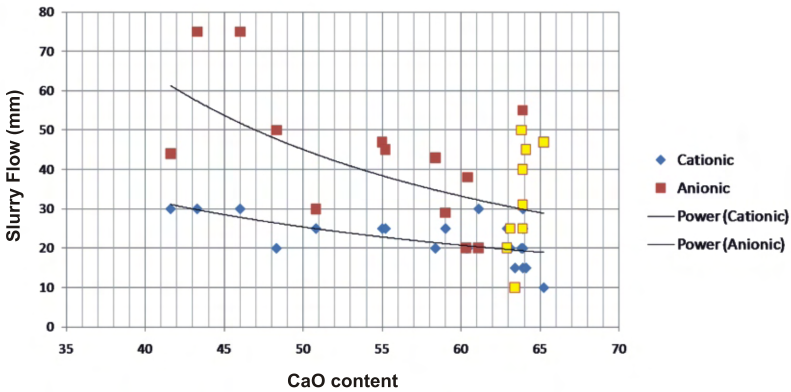


Figure 5: Slurry flow versus CaO content

NOTE

Yellow markers represent cements classified as CEM1, mixed with anionic emulsion.

3.3 Bituminous binders and additives

3.3.1 General

Emulsions used for slurries and microsurfacings in South Africa are generally manufactured from 80/100 penetration grade bitumen. Microsurfacing emulsions used for rut filling applications are often manufactured with 60/70 penetration grade bitumen to yield a stiffer end product.

3.3.2 Anionic stable grade emulsions

Anionic stable grade emulsions are normally used for conventional slurries. Due to no attraction between the bitumen and the aggregate, curing (breaking) occurs only as a result of normal water evaporation. The attraction between the aggregate and bitumen and the principle of curing is shown in Figure 6.

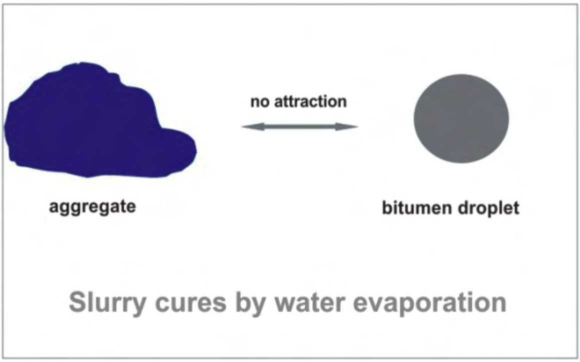


Figure 6: Conventional slurry composition

3.3.3 Cationic stable grade emulsions

Cationic stable grade emulsions are used to a very limited extent in certain parts of the country where quartzitic aggregates are predominant.

3.3.4 Special cationic emulsions

Special cationic emulsions that contain no polymers, are also used for rapid setting slurry mixtures. Curing (breaking) occurs as a result of normal water evaporation. However, the speed of curing is increased due to the stronger attraction between the positively charged binder and the negatively charged aggregate and the action of cement, which upsets the pH balance of the acidic emulsion. The attraction between the aggregate and bitumen and the principle of curing is shown in Figure 7.

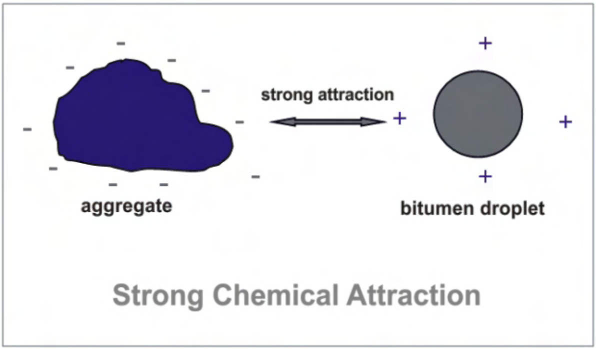


Figure 7: Rapid setting slurry composition

3.3.5 Microsurfacing emulsion

Microsurfacings consist of aggregate, cationic emulsion, latex (polymer) and additional chemicals to control the speed of curing (breaking). A stronger adhesion between the binder and the aggregate is facilitated through the addition of a polymer. The attraction between the aggregate and bitumen and the principle of curing is shown in Figure 8.

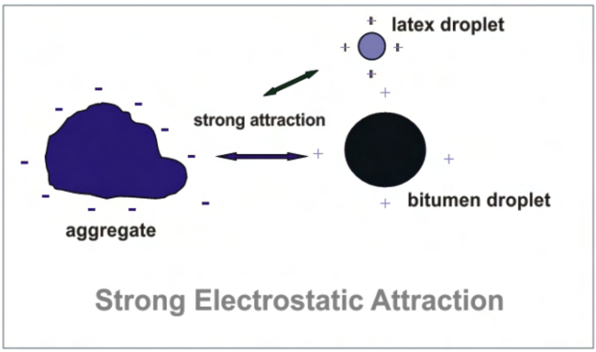


Figure 8: Composition of microsurfacings

3.4 Mix design

3.4.1 General

Based on experience and performance of slurries in South Africa, recommendations for designs are discussed under the following headings:

- Slurry type and property selection;
- Conventional slurry design
  - Simplified design (determining appropriate binder contents for slurry mixes on low volume roads when aggregates conform to standard COLTO specifications)[12];
  - Detailed design (determining appropriate binder contents for slurry mixes on high volume roads and/or when aggregates do not conform to standard COLTO Specifications)[12];
- Design of rapid setting slurries and microsurfacings;
- Useful tests
  - Water demand;
  - Mixing and coating test;
  - Additional tests and evaluation for rapid setting slurry and microsurfacing.

3.4.2 Slurry type and property selection

The selection of the appropriate slurry type is discussed under Section 2. However, based on the traffic volumes, loads, tyre pressures and conditions, the designer also has to formulate his/her strategy and evaluate the impact of a lower or higher binder content e.g. a much higher binder content could be accommodated on a low volume road without the risk of bleeding or deformation.

3.4.3 Conventional slurry design

Historical approaches

The different applications of slurry seals have led to different design approaches, utilised for conventional binder slurry mixes over many years in South Africa.

The designs were either based on asphalt design methods, semi-empirical methods or on experience taking into account:

- Aggregate grading;
- Fattiness/dryness of the existing surface;
- Climatic zones;
- Traffic.

The reader is referred to TRH3[5], *Materials Manual* of the Western Cape Department of Transport[4] and the Gautrans *Seal Design Manual*[14]. A Modified Marshall Method, as still used by some South African practitioners is provided in this document as Appendix A.

Current recommendations

The current recommendation, as supported by the majority of South African practitioners, provides for either one of two methods namely:

- Simplified design method;
- A detailed design method.

Simplified design method

The recommended new simplified method is considered applicable for lower volume roads (typically 1500 vpd/direction), provided the aggregate is well graded and within the recommended envelopes (refer Table 2).

This method originated from the Gautrans design method, which was developed by a group of experienced practitioners, experimental work and visual performance evaluation. An “appropriate binder content” (stable grade 60% emulsion) for a specific type of grading and traffic situation, within a specific climatic zone, is selected. The climatic zones identified by the former Transvaal Roads Department coincide well with “Wet, Moderate and Dry” macroclimatic regions as defined by the Weinert N values[15] of less than 2, 2-5 and more than 5.

The process is summarised as follows:

Steps

1 Obtain recent and relevant traffic data and convert to Equivalent Light Vehicles per lane per day (ELV) where 1 heavy vehicle = 40 light vehicles. Any vehicle other than light delivery, car or minibus should be considered a heavy vehicle.

2 Assess the existing surface according to TMH9[11] (fattiness/ dry-brittleness)
- Dry is defined by a degree of 3 or more (refer Appendix C);
- Recent rejuvenated surfaces are considered as “fatty”;
- Bleeding or slick surfaces should not be treated with a slurry seal.

3 Verify the purpose and type of slurry mix

4 Verify material grading within specification

5 Select the relevant macro-climatic area (Figure 9)

6 Use Figure 10 to select the appropriate binder (emulsion) content

7 Select the appropriate filler content based on the dust (-0,075) content or by the “Mixing and coating test” (refer Section 3.2.6 and Section 3.4.5)

8 Determine the water demand for the selected application, using the cement that will be used on site (refer Section 3.4.5).

NOTE

Although Figure 10 could recommend emulsion contents of up to 330 ℓ/m^3 of dry sand, based on real experiments on low volume roads, current practitioners recommend lower upper limits e.g. maximum of 280 ℓ/m^3 for fine slurry on a low volume road. The lower border of areas shaded in red represent maximum emulsion contents as recommended by current practitioners.

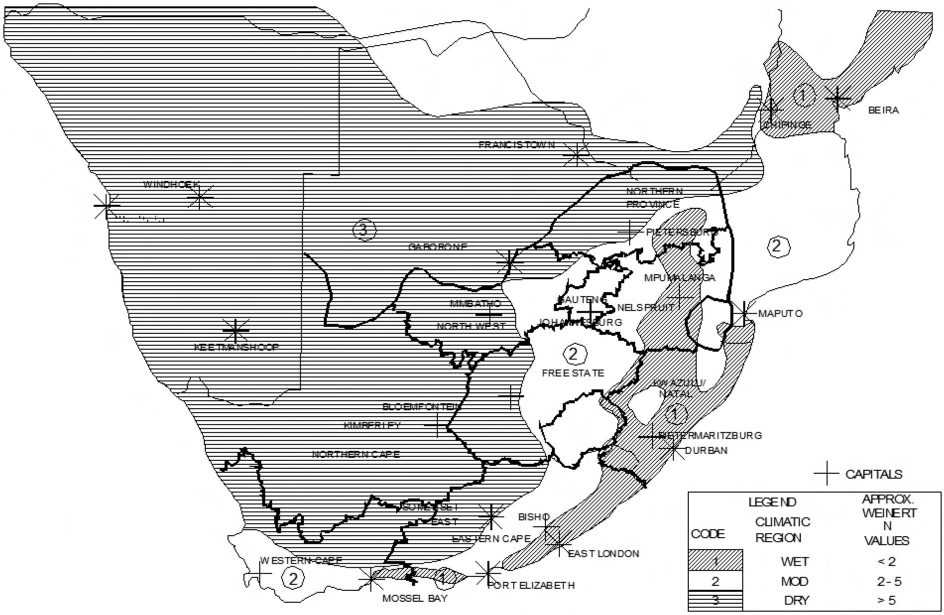


Figure 9: Macroclimatic regions of southern Africa

Example:

For a medium graded slurry in a moderate to dry environment on an existing dry surface, with 2500 ELV/l/d, the appropriate emulsion content world be in the order of 240 ℓ/m^3 (refer Figure 10).

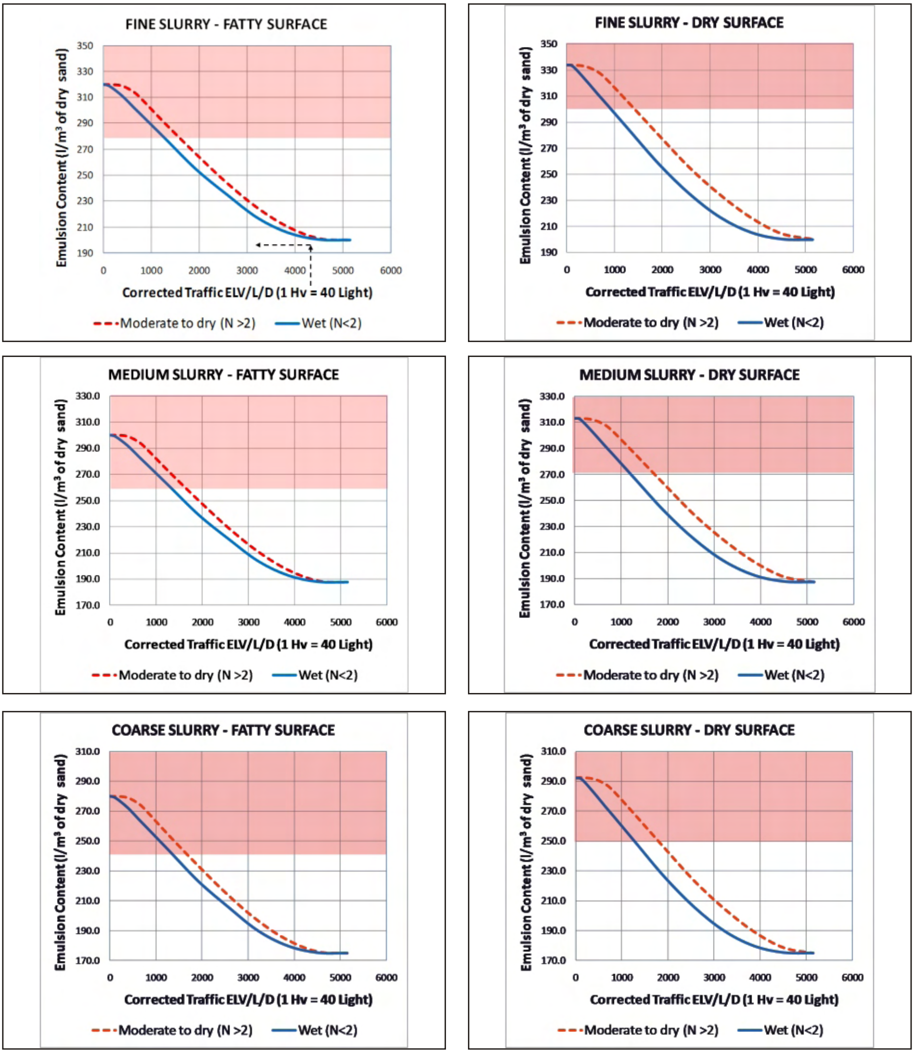


Figure 10: Simplified design curves

Detailed conventional slurry mix design method

A detailed design is recommended for high traffic situations and/or non-standard aggregate and requires comprehensive testing. The process is summarised as follows:

- Sample preparation and compaction;
- Preliminary evaluation;
- Abrasion testing;
- Determining of voids filled with binder;
- Evaluation and decision.

Sample preparation

- Several slurry mixtures are made up, varying the emulsion content from 180 ℓ/m^3 to 240 ℓ/m^3;
- The slurry mixtures, each 200g are poured into Marshall briquette moulds to approximately 15 mm in depth;
- Samples are dried overnight at 60°C to allow water evaporation;
- Samples are then compacted using the Marshall hammer – 150 blows (only one side).

Photograph 8: Marshall mould

Photograph 9: Spacer block for mechanical compaction

In case automatic compaction equipment is used, a spacer would be required to obtain a similar height to a normal Marshall briquette, as shown in photographs 10 and 11.

Photograph 10: Spacer block in mould

Photograph 11: Similar height

Photograph 12: Pour slurry in mould

Photograph 13: Slurry before compaction

Preliminary evaluation

During the compaction of the briquettes the extent to which plastic deformation occurs should be recorded. After compaction the briquettes are broken in two and the colour and pliability recorded.

The ideal binder content would result in:

- No plastic deformation at the edges (between the hammer and the side of the mould);
- Dark grey to black coloured specimens, slightly pliable when broken in two.

NOTE

A dull brown colour indicates too low binder content.

Photograph 14: Preliminary evaluation of briquettes

Abrasion testing

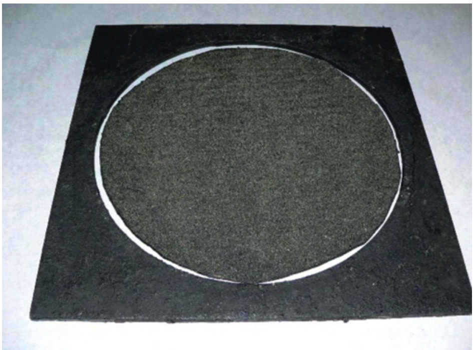
The visual evaluation of compacted samples could result in a range of binder contents being acceptable (typically three percentages of bitumen e.g. 7%, 8%, 9%). Mixes with the selected binder contents are then prepared and abraded using the Wet track abrasion test.

The apparatus is shown in photograph 15.

Photograph 15: Using the wet track abrasion test apparatus

Steps taken in the preparation of the specimens are as follows:

1. Cut 300 mm diameter of suitable material (felt roof leaking repair material works well).
2. Pour the slurry mix (approximately 800g on the felt material).
3. Spread the slurry mix without slushing the fines and emulsion to the top.
4. Allow the sample to dry for approximately 24 hours and weigh accurately to 0,1 g.
5. Soak the prepared sample for 1 hour in water at 25°C.
6. Abrade the sample (ASTM 3910)[16].
7. Dry the abraded sample in a ventilated oven at 60°C to constant weight and weigh accurately to 0,1 g (typically 24-48 hours).



Photograph 16:
Cut 300 mm diameter felt material

Photograph 17:
Pour the slurry mix on the felt

**Photograph 18:
Spread the slurry mix evenly**

**Photograph 19:
Allow prepared sample to dry**

Dried specimens are soaked for 1 hour in water and then abraded. The loss of aggregate is then determined and the performance evaluated. The performance in terms of aggregate loss of specimens with different binder contents is often quite obvious/visible as shown in photograph 20.

Photograph 20: Abraded specimens

Determine the voids filled with binder

Should the initial briquettes be damaged at this stage, additional mixes could be made up with different binder contents resulting in low mass loss and compacted. SANS 3001-AS10 is then used to calculate:

- Bulk relative density of the briquette;
- Percentage of voids in the mix;
- Voids in mineral aggregate;
- Percentage of voids filled with binder.

Evaluation and decision

Minimum binder content

Figure 11 shows the mass loss after abrasion on a specific aggregate grading with different binder contents. The arrow depicts the binder content whereafter an increase in binder does not alter the mass loss significantly. Within a range of appropriate binder contents, this percentage is considered to be the minimum binder required for any situation (in this case 7% bitumen calculated to the mass of dry aggregate).

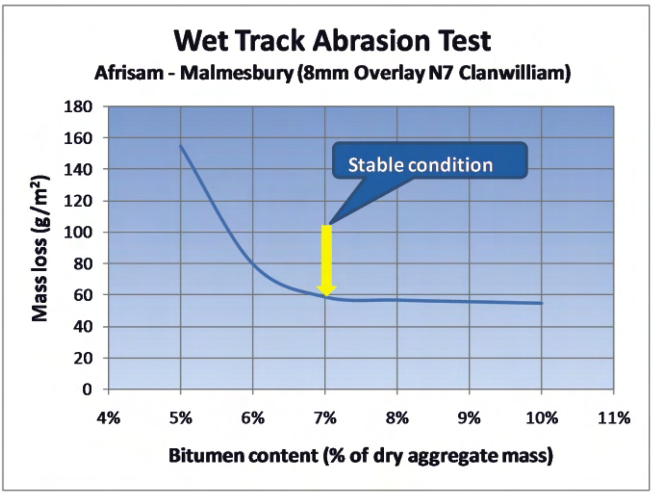


Figure 11: Mass loss versus bitumen content

Maximum binder content

The maximum binder content is a function of the purpose of the slurry and the conditions under which it has to perform.

Photograph 21: Briquettes with different binder contents

Visual evaluation of the briquettes shows a variation from a brown and dull colour at 5% binder to a shining specimen with some plastic deformation at 10%. For this particular grading (aggregate mixture) the material stuck to the Marshall hammer at higher percentages than 10%.

Using TMH1 (Method C3)[2] the voids filled with binder is determined for each of the prepared briquettes and plotted against the binder content. In addition, the visual observations regarding the briquette condition is added (brittle, normal, fatty) to define the range of "voids filled with binder" providing a "normal" performance.

Superimposing the observations on the "mass loss versus binder content" graph (refer Figure 11), provides a range of binder contents in a "normal" performance category.

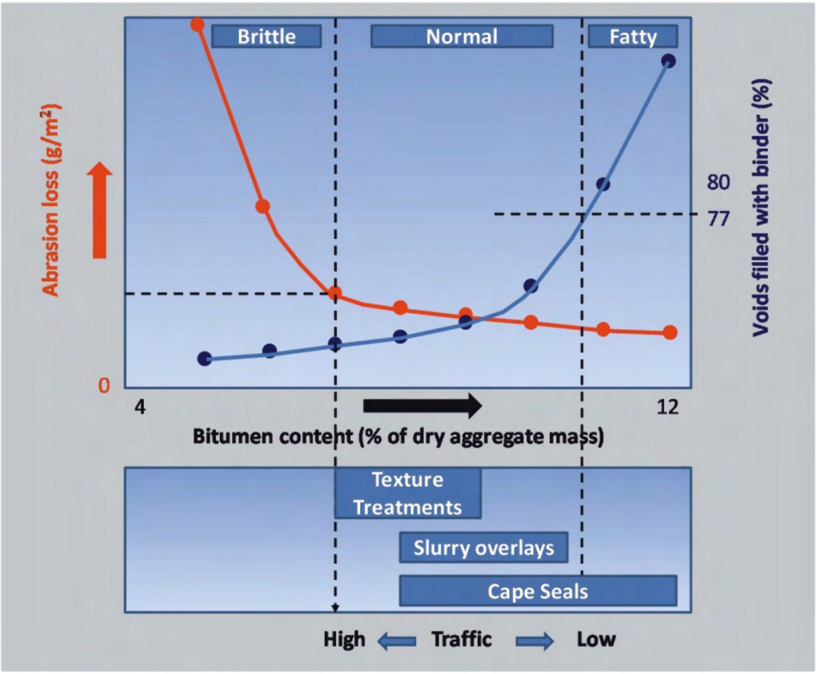


Figure 12: Combined information for decision making

A final decision is taken at this stage for conventional slurries to select the design binder content, taking account of:

- Traffic conditions;
- Timing of and type of surfacing to follow the slurry application;
- Construction process and technique.

Traffic conditions

In terms of Equivalent Light Vehicles per lane per day (ELV) the following guidelines apply:

- High - >8000 ELVs;
- Low - <2500 ELVs.

Timing and type of surfacing to follow the slurry application

Texture treatment and/or rut filling are often done just prior to resealing operations. The typical minimum curing periods (COLTO)[12] are as follows:

- Texture treatments – 6 weeks;
- Rut filling using rapid setting slurry –12 weeks.

The higher the traffic and the quicker the follow-on seal must be applied, the drier (less binder) the mix should be.

NOTE

Should circumstances require earlier sealing after the pretreatment e.g. close to winter, ball penetration testing could be done to monitor the hardening of the slurry. Commencing with seal work is not recommended if the ball penetration during the warmest part of the day is still more than 2 mm.

Construction process and technique

Texture slurry is normally applied by hand squeegees, working the fine slurry into the voids between the existing seal aggregate. However, it is sometimes allowed to use a slurry box for the texture slurry application, which could result in slurry covering the existing seal aggregate. In this particular situation, the binder content should be lower as the vehicles drive directly on the new slurry.

3.4.4 Design of rapid setting slurry and microsurfacing

The design of rapid-setting slurries and microsurfacings is considered highly specialised and is therefore not addressed in detail.

Although the basic principles for design of conventional slurries apply, the selection and addition of additives for different situations complicates the design dramatically. Therefore it is recommended that the design of rapid setting slurries and microsurfacings be left to the suppliers of these products.

3.4.5 Useful tests

Water demand (consistency test)

The mixture of crusher dust, cement and emulsion requires additional water to improve the workability. A general rule of thumb suggests an additional water demand of approximately 80% of the total emulsion content. However, the required workability is dependent on the specified procedure and is measured by the flow of the mixture on a plate (ASTM consistency test)[16].

Photograph 22: Slurry flow measurement

> **NOTE**
>
> If the water demand exceeds the quantity of emulsion, the end product is expected to perform poorly.

Typical flows required for different applications are as follows:

Table 5: Recommended slurry flow for different applications

Application	Target Flow
Slurry bound macadam	60 mm
Texture treatment or Cape seals	30-40 mm
Slurry overlay	20-30 mm
Microsurfacing	10-20 mm

NOTE

The number does not represent the radius of the slurry on the plate.

Mixing and coating test

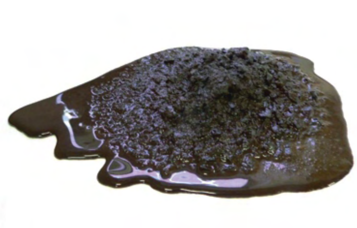
The purpose of this test is to determine the stability of the mix and appropriate percentage of cement or lime (1 – 2%) to obtain a creamy mix without segregation.

NOTE

Experience indicates that:

- 1% filler (cement or lime) is sufficient when the dust content (<0,075 mm) is more than 7% of the dry aggregate mix;
- 1,5% filler is required when the dust content is less than 7%.

Photograph 23: Mixing of slurry components



Photograph 24:
Too low filler content

Photograph 25:
Correct filler content

Additional testing for rapid curing slurries and microsurfacings

General

Similar to conventional slurry, the design of microsurfacings require evaluation of the aggregate grading and properties as well as the minimum binder content to prevent ravelling. However, due to the different curing process (chemical), additional testing is required to determine the need for and quantity of chemicals (usually amines) to obtain an appropriate mix that will allow sufficient time to mix before breaking.

Effect of additive on mixing and setting time

Dependent on the purpose of the microsurfacing, climatic conditions, equipment and traffic accommodation requirements, more or less additive could be introduced in the mix. A balance should be obtained to ensure no early breaking during construction but sufficient additive to open traffic as early as possible.

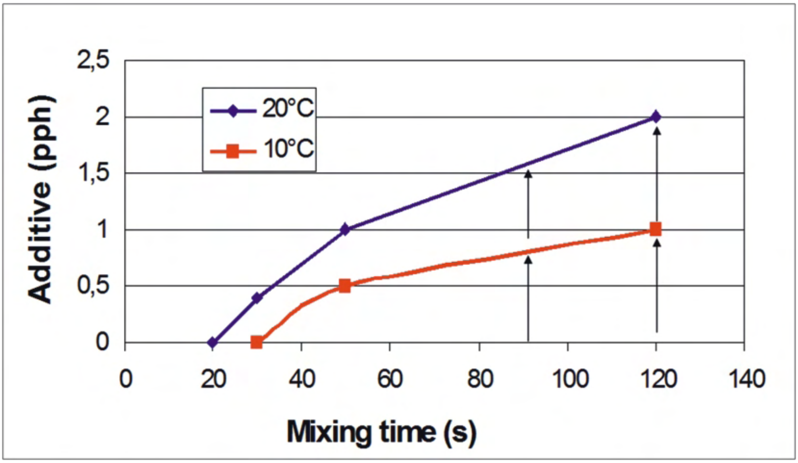


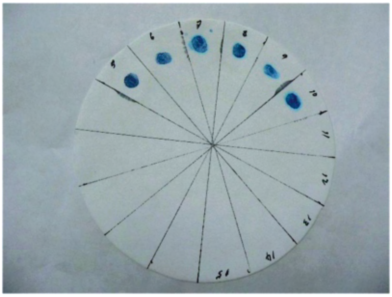
Figure 13: Mixing time before breaking

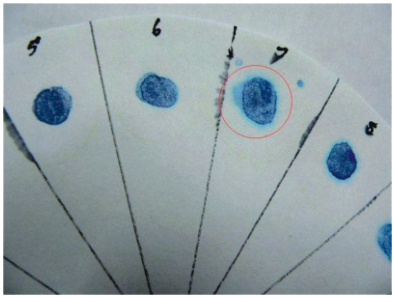
> **NOTE**
>
> The mixing time before breaking for a microsurfacing should be at least 90 seconds.

Preparing samples with the recommended quantity of the "break control" additive and visual observation would confirm if the design is appropriate (refer photograph 27 and photograph 28).

Methylene blue test

The purpose of this test is to verify the degree of electrostatic attraction between emulsion and the aggregate.





Photograph 26: Effect of Methylene blue addition

NOTE

More or less positively charged break control additive could be added to obtain a workable mix. (Methylene Blue values of 6-8).

Photograph 27: After 5 minutes

Photograph 28: After 15 minutes

4 CONSTRUCTION

4.1 Mixing and application equipment

4.1.1 Batch mixing

The slurry mix is made at a dedicated plant by:

- Adding most of the mixing water to the mixer;
- Weighing the crusher sand and subtracting the predetermined mass of moisture;
- Feeding the sand into a mixer;
- Adding the predetermined amount of filler (cement or lime);
- Adding the design volume of stable grade emulsion;
- Adjusting the final consistency by adding a small quantity of water to obtain the required flow, if required.

Photograph 29: Batch mixing plant

NOTE

Storage tanks for emulsion should be covered e.g. shade nets to reduce the temperature during day time as high emulsion temperatures will result in early breaking of the slurry.

4.1.2 Continuous mixing slurry machine

Self propelled machines are available and able to:

- Load the crusher sand;
- Carry all raw material components;
- Measure material quantities and feed them to a pug mill;
- Mix the slurry continuously;
- Spread the slurry via an augured spreader box.

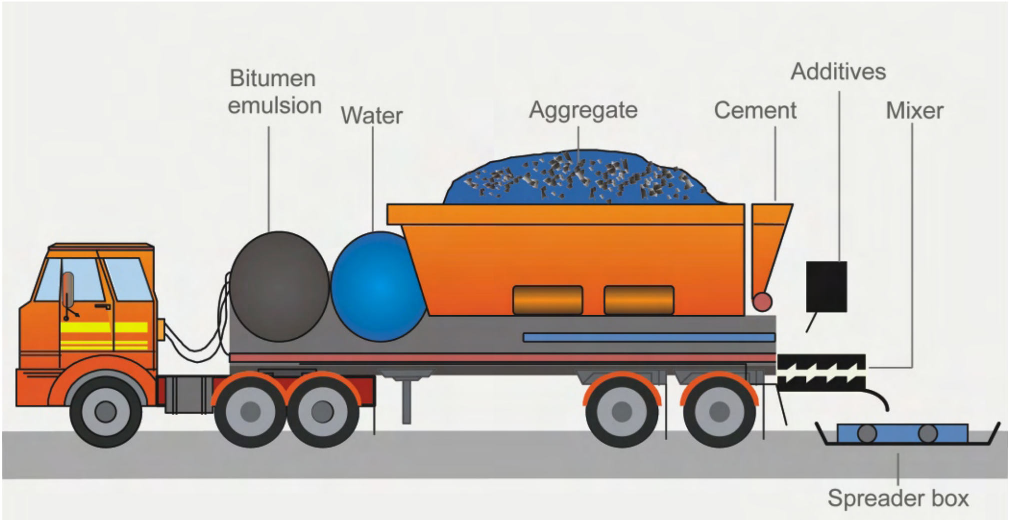
Photograph 30: Continuous mixing slurry machine

The slurry machine as shown in photograph 30 has the following special features:

- Self loading with carrying capacity of 8,5 m^3;
- Mixing controls;
- Hydraulic driven pump for emulsion.

The relevant individual components of the continuous slurry machine are shown in Figure 14.

Figure 14: Continuous mixing process



Spreader boxes

Different types of spreader boxes could be fitted to the continuous mixing machine.

Examples are:

- Fixed width;
- Variable width.

> **NOTE**
>
> 1. COLTO[12] specifies an adjustable width spreader box (1,5m-4,0m)
> 2. Fixed 1m spreader boxes are used for filling ruts.

The spreader box should be fitted with:

- Long metal skids to ride over undulations/irregularities on the road surface and distribute the weight evenly not damaging the existing surface;
- Soft rubber belting attached to the framework to prevent slurry from spilling past the sides of the box;
- A striker rubber at the exit of the spreader box to provide the necessary finish to the slurry layer being placed on the road;
- Appropriate height adjustment to vary the thickness of the slurry layer.

Photograph 31: Fixed width

Photograph 32: Fixed width (1m) for rut fill

**Photograph 33:
V-shaped variable width**

**Photograph 34:
Telescopic auger variable width**

4.2 Construction guidelines

4.2.1 General

The success of a slurry or microsurfacing is highly dependent on the material quality, accurate mix proportions, mixing process, placing and climatic conditions during construction.

4.2.2 Aggregate bulking

Effect of moisture

Ideally, the sand used for the slurry seal should be dry before the required volume of emulsion is mixed in. The volume of sand increases as the moisture content increases, after which, when saturated, it decreases again to approximately its original dry volume. Crusher sand conforming to the grading specifications for slurry could expand to 30% of its dry volume. This phenomenon creates a risk of too much binder being added to the slurry mixture.

A moisture/volume expansion curve can be derived in a laboratory for a specific sand, by adding water to dried samples and measuring the change in volume. Figure 15 shows an example of the volume expansion difference between a coarse and a fine sand.

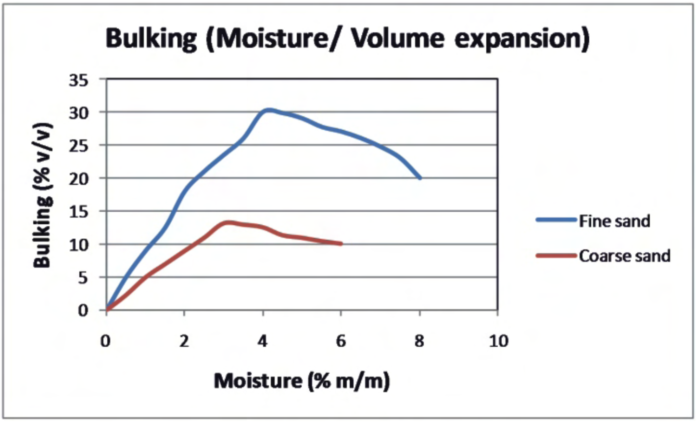


Figure 15: Bulking of sand due to moisture

Determining the bulking factor

A practical method of determining the approximate moisture/volume expansion of sand is as follows:

a) Fill a container of known volume with sand from the stockpile (tap lightly 10 times) and weigh;

b) Dry the sand by spreading it on a clean surface and heating (e.g. with a gas burner);

c) Determine its dry volume and mass;

d) Calculate the moisture content and volume expansion.

Example

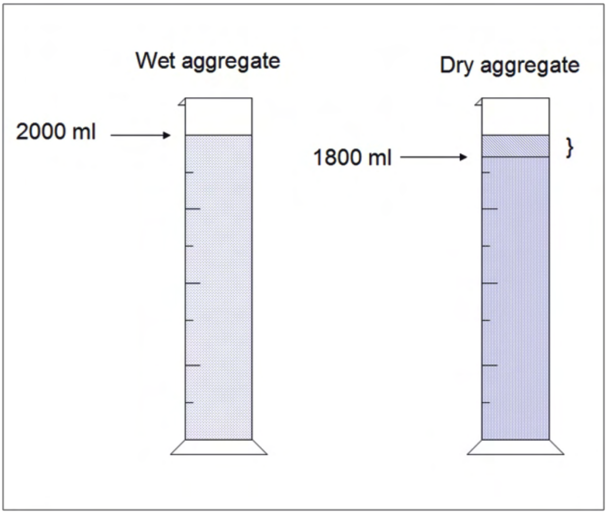


Figure 16: Determination of the bulking factor

Design correction

The dry/wet ratio in the above example = 1800/2000 = 0,90

If 225 litre of emulsion per cubic metre of dry aggregate is required according to the design, then the required emulsion volume for the moist aggregate is:

$$225 \times 0{,}9 = 203\ \ell/m^3$$

Alternative method

a) Fill a container of known volume with sand from the stockpile (tap 10 times lightly) to required volume level;

b) Saturate the sample with water and wait for sand in suspension to settle;

c) Determine the reduced volume of sand.

Although not necessarily correct, the saturated volume is taken as being similar to the dry volume for calculation of the required amount of emulsion.

NOTE

- The method of filling the aggregate bin of the slurry machine might not represent a similar packing of the moist sand
- Weigh batching ensures better control.

4.2.3 Climatic conditions

During and soon after placing, slurries could be sensitive to very cold and very hot temperatures, high humidity and rain. Specifications (COLTO)[12] and additional guidelines are as follows:

- Conventional slurry shall not be applied at an air temperature of less than 7°C when temperatures are rising, or less than 13°C when temperatures are dropping. When cold winds are blowing, these limits should be increased by approximately 5°C;

- Experience indicates that conventional slurries should not be applied when the humidity exceeds 70%;
- Rapid setting slurries/microsurfacings are normally designed to be applied in air temperatures of between 4°C and 40°C, as well in damp conditions;
- During hot weather slurry operations should be suspended. Road surface temperatures in excess of 60°C would typically result in the slurry breaking too quickly e.g. in the spreader box.

4.2.4 Slurry box application

A slurry box is normally used for application of conventional coarse slurries or rapid setting slurries/microsurfacings. The following guidelines are applicable:

- When necessary or specified a tack coat consisting of a 30% diluted emulsion should be applied prior to the application of the slurry mix;
- The preferred flow for coarse slurry is considered to be in the order of 20mm;
- While the slurry machine is placing the slurry a light spray of water is applied by means of the water spray bar mounted in front of the machine;
- A stiff rubber blade (9,5 to 19,0 mm) should be mounted to the rear of the slurry spreader box and should run on adjustable sliding tracks to provide the necessary finish of the slurry seal;
- With the application of coarse slurry seals, this rubber blade could be replaced by a steel plate. This plate ensures that unevenness (e.g. corrugation) is removed;
- When a microsurfacing (quick set slurry seal) is applied, an auger or mixing paddles are fitted in the spreader box to assist with the mixing process and to spread the quick set mix uniformly over the full width of the spreader box;
- Specific attention should be given to joints using hand squeegees;
- The slurry seal should be finished off by dragging a wet burlap over the full width behind the spreader box;

- Roller compaction is required using a heavy (+ 20 ton) pneumatic roller, minimum three passes or preferably until the Marvil water permeability[8] is less than 1 ℓ/h on conventional coarse slurry and 0,5 ℓ/h on rapid-setting slurry and microsurfacing;
  - Rolling should only commence when the slurry has set sufficiently;
    - Rapid setting coarse slurry shall be sufficiently stable to be rolled after 45 – 60 minutes;
    - For conventional coarse slurry rolling can start as soon as clear water can be pressed out of the slurry mixture with a piece of paper without discolouring the paper;
  - The layer should not show significant displacement under the rollers;
  - Shaded areas and/or thick layers should be checked for wet patches;
  - Rolling shall proceed from the haunch, kerb or channel and lapping while working to the crown or upper end of cross fall/super-elevation of the road;
  - Rollers shall not be permitted to stand on newly laid coarse slurry until it is fully compacted and has set completely.

NOTE

Application of slurry for Cape seals with a slurry box is not recommended.

4.2.5 Hand application

General

Hand application of slurry is normally done during the construction of Cape seals, texture treatments, slurry-bound macadam seals or slurry overlays in confined areas. The following guidelines are applicable:

Cape Seals

Application of first layer of slurry

- The slurry should be applied, preferably not less than four days nor more than four weeks after the penetration layer and/or fog spray;
- When the penetration/fog-spray is dry (cured) the surface is given one complete roll with a 6 to 8 ton steel wheel roller;
- Rolling should preferably be done as early as possible in the morning in order to prevent pick-up;
- Before the slurry is applied, the road surface should be lightly sprinkled with water;
- Under no circumstances must free water be present on the surface when the slurry is applied and no additional water should be added to the slurry on the road to improve the workability;
- The consistency of the slurry mix should be controlled using the ASTM Method D3910[16] with a flow of 30 to 40 mm at the time of placing.

> **NOTE**
>
> The slump could change during the day as the temperature rises. Regular checks are required and adjustments made at the batching plant.

- The slurry must be applied by means of hand held rubber squeegees in a layer of sufficient thickness to fill the voids between the chips while leaving just the top of the chips exposed;

- The spreading of each batch must be completed before the next batch is discharged;
- It is desirable that the slurry have a wet consistency and it is essential that it is applied with to-and-fro as well as sideways movements of the rubber squeegees to ensure that the slurry enters all the interstices;
- The first slurry layer should be spread to the full width of the chips;
- After the emulsion has cured sufficiently the layer should be rolled properly with heavy pneumatic tyred rollers
- Rolling must not be done later than on the first working day after the slurry was placed. Roller compaction is recommended using a heavy (+ 20 ton) pneumatic roller (minimum of three passes);
- After the rolling has been completed, the layer can be opened to traffic.

Application of the second layer or slurry

- Preferably within four weeks after the first slurry was opened to traffic, the second slurry layer can be placed as described above for the first slurry. The second layer of slurry should only be applied after the first layer has dried (minimum of 24 hours);
- The second slurry should be spread to the full width of the primed surface;
- The edges should be finished off in a straight line and the final surface must be dense with a uniform appearance with just the tops of the aggregate exposed after rolling;
- In case of the second layer of the 19 mm Cape Seal, pneumatic rolling is recommended until the Marvil water permeability[8] is less than 1 ℓ/h.

- Prior to placing the slurry the road surface should be dampened, particularly during hot weather;
- The preferred flow for handwork is considered to be 30 mm – 40 mm;
- Manageable proportions should be dumped at a time and spread by trained operators;
- Segregation could occur if the slurry is moved too far, resulting in binder contents different to the design;
- The slurry must be worked to-and-fro with the aid of the squeegee to ensure complete filling of the voids in the existing aggregate/seal matrix, ensuring that the tops of the large aggregate are still visible;
- The slurry seal should be finished off by dragging a wet burlap over the full width;
- Although rolling with a pneumatic roller is preferable, the thin layer between the existing large aggregate particles is easily compacted by normal traffic action.

4.2.6 Quality control

Quality control should be executed during all phases of design and construction with the main activities as summarised below:

- **Design process**
  - Slurry type selection;
  - Material selection;
  - Testing and evaluation;
  - Adjustment on site. In addition to the moisture expansion adjustment, experience has shown that the crusher sand delivered to site could vary drastically, requiring a redesign. The original design might have specified the addition of natural sand to specific proportions. The final material after mixing should be checked and if necessary, the mix should be redesigned.

- **Construction**
  - **Equipment**
    - Accuracy of weigh batching;
    - Checking equipment for fuel leaks and proper functioning.
  - **Stockpile management**
    - Free-draining, well compacted area;
    - Covering stockpiles to prevent moisture variation and segregation.
  - **Sampling, testing and acceptance of materials on site (also refer Appendix D)**
    - Correct sample procedures;
    - Testing and acceptance of the binder according to specifications;
      - The anionic emulsion shall comply with the requirements of SABS 309[13];
      - The cationic emulsion (slow-set) shall comply with the requirements of SABS 548[13];
      - Microsurfacing emulsions shall comply with the requirements of AC-E1 or AC-E2 polymer modified emulsions, as stipulated in Table 11 of TG1 – *The use of modified binders in road construction*;
      - The base bitumen used in the emulsion shall be a 80/100 penetration grade bitumen or in the case of some microsurfacing emulsions, 60/70 penetration grade bitumen, which complies with the requirements of SABS 307[13];
      - Bitumen content in the slurry mix;
    - Testing and acceptance of the aggregate according to specifications.

Table 6: Aggregate properties

Application	Test/Property	Test Method
Slurries and microsurfacing:	Grading	SANS 3001-AG10:2011[12]
	ACV	TMH1 B1:1986 (SANS 3001-AG9:2010)
Crusher dust, sand	Sand equivalent	TMH1 B19:1986
	Immersion Index	TMH1 C5:1986
	Plasticity	SANS 3001-GR10:2009
	Methylene blue test	SANS 1243

NOTE

Some road authorities specify a tolerance after the target grading has been established. Example in Table 7.

Table 7: Allowable variation from target grading

Aggregate passing sieve size (mm)	Tolerance (+ or –)
5 and larger	5%
2	4%
0,300	3%
0,075	1%

- **Mixing**
  - Visual inspection ensuring a homogeneous mix throughout the spreader box;
  - Effective operation of auger in microsurfacing rut fill spreader box.
- **Application and rolling**
  - Refer to guidelines (Sections 4.2.4 and 4.2.5);
  - Thickness/quantity;
  - Uniformity.

- **Opening to traffic**
  The road can only be opened to traffic when the slurry/ microsurfacing is stable and properly cured. A simple but effective test is to use a paper towel to check for uncured emulsion.


Photograph 35: Checking for uncured emulsion

- **Trial section**
  The construction of trial sections before large scale application is considered good practice to verify the
  - Ability of the contractor;
  - Condition and effectiveness of equipment;
  - Workability and setting of the mix;
  - Appropriate stage to provide initial compaction with a pneumatic roller and/or to allow trafficking.

4.2.7 Typical problems

Balling

Balling as shown in photograph 36 can occur when rapid breaking occurs, and could be caused by too high a temperature of the aggregate or binder. This will be even more pronounced if the fines content is on the high side within the grading envelope.

Photograph 36: Balling

Slow break

The breaking of conventional slurries is dependent on temperature and humidity influencing the evaporation of water from the applied product. Experience suggests not to apply conventional slurry when the humidity is more than 70% or the ambient temperature is less than 7°C.

Microsurfacings are designed for rapid setting with the rate of breaking dependent on the additives introduced for this purpose.

Too rapid break

Apart from aspects mentioned under “Balling”, the road surface temperature could also influence the speed of breaking. Experience suggests stopping slurry/microsurfacing application when the road surface temperature rises above 55-60°C.

Segregation

Segregation of the mix could occur as a result of an ineffective catalyst (normally lime or cement). During the consistency test, the potential for segregation could easily be observed.

> **NOTE**
>
> Cases have been noted where neither lime nor cement is effective. The suppliers of the emulsion should then recommend an alternative chemical compound to be used to overcome the problem.

Segregation often occurs during hand application as a result of:

- The mix being moved too far from the point of offload;
- Too coarse grading used as a texture slurry or Cape Seal slurry.

Photograph 37:
Segregation (too coarse grading for texture treatment)

Bleeding of Cape seals

Cape seals often tend to become fatty (not necessarily uniform). Some of the main causes for this phenomenon are:

- Too high binder content (design);
- Not allowing the tack coat or cover spray to cure properly before applying the slurry;
- Not allowing for moisture expansion;
- Segregation due to moving slurry too far from point of off-load;
- Allowing traffic onto the slurry too soon.

Photograph 38: Influence of tack coat on slurry seal

Photograph 39: Too high binder content

Photograph 40: Poor quality control on batch of Cape Seal slurry

Delamination of slurry

Delamination of slurry can occur as a result of:

- Too low binder content;
- Dirty surface before slurry application;
- Permeability problems allowing water penetration and pore pressure development. Recommendations in this regard are:
  - Sufficient rolling before opening to traffic;
  - Do not fill ruts on a modified binder seal. First fill the ruts and then apply the modified binder seal.

Photograph 41: Delamination

Ravelling

Ravelling typically occurs as a result of:

- Too low binder content;
- Too high natural sand content.

Photograph 42: Ravelling of slurry in wheel track

Colour variation

Colour variations in slurry seals can occur as a result of any of the following reasons:

- Variation in bitumen content;
- Variation in the grading of the sand;
- The direction of movement of the slurry machine;
- Variation in the quality of the emulsion;
- Rain during or shortly after placement of the slurry;
- Variation in filler content;
- Variation in emulsifier (phosphoric acid versus hydrochloric acid).

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APPENDIX A

Modified Marshall Method for design of conventional slurry mixes

(Documented By P Fourie – Soillab)

Modified Marshall Method for slurry design

This method is used to determine an appropriate binder content for use in slurry mixtures. Although this method was derived for coarse mixtures it has also proven to be successful in fine mixtures. This method makes use of the Marshall Method for the compaction of briquettes, as explained in SANS 3001-AS1[2]. Briquettes are formed from materials, of which the emulsion content is increased in increments of 20 ℓ/m^3.

Stepwise procedure:

- Create a sufficient quantity of briquettes ensuring that all the Marshall properties are adhered to as well as indirect tensile strength, submersion index and creep properties;
- The composition of mixtures with different emulsion contents are based on 1 m^3 loose sand. (Uncompacted/Loose Bulk Density – TMH1: Method B9);
- Assume the loose bulk density is 1 600kg/m^3. Calculate the quantity cement that needs to be added, for example 1,5%=24kg. For the purpose of this test, emulsion contents of 160 ℓ, 180 ℓ, 200 ℓ, 220 ℓ, 240 ℓ, are chosen that will be mixed with 1 m^3 crusher dust;
- A table can now be put together for use in the creation of briquettes.

Table 8: Guidelines for the creation of briquettes

Emulsion in mixture	(ℓ)	160	180	200	220	240
Slurry sand 1 m^3 (uncompacted)	(kg)	1600	1600	1600	1600	1600
Cement 1,5%	(kg)	24	24	24	24	24
Water	(ℓ)	120	112	104	96	88
Net binder for 60% emulsion	(ℓ)	96	108	120	132	144
Net binder for 60% emulsion Binder head density = 1025kg/m^3	(kg)	98,4	110,7	123	135,3	147,6
Net binder in mixture	(%)	5,71	6,38	7,04	7,68	8,33
Laboratory mixtures						
Emulsion	(g)	111,47	124,52	137,38	150,06	162,56
Slurry sand	(g)	1114,72	1106,82	1099,03	1091,34	1083,77
Cement	(g)	16,72	16,60	16,48	16,37	16,26
Water	(g)	83,60	77,48	71,43	65,48	59,61
Net Binder	(g)	68,55	76,58	84,49	92,29	99,98

- The amount of water added to attain workability is determined, with the slurry consistency test, in order to achieve the correct consistency. Laboratory mixtures are composed in such a manner as to achieve a mixture of 1200g after the emulsion has broken and the water has evaporated. In the example shown above, to attain an emulsion of 160 ℓ the following mix is required, 1114,72g sand, 111,47g emulsion, 16,72g cement and 83,60g water. The mixture is left in a bowl so that the emulsion can break and the water can evaporate.

Thereafter the samples are placed in an oven and briquettes compacted when the temperature reaches 135°C (compaction temperature). The briquettes are compacted in a Marshall mould by means of 75 blows with the Marshall hammer on both sides. Briquettes are compacted with all the mixtures as set out in the table above;

- For each of the binder contents a mixture is made to determine the maximum theoretical relative density (Method SANS 3001-AS11);
- Determine the bulk relative density of the compacted briquettes (SANS 3001-AS10) and calculate the percentage air voids for each of the binder contents;
- Thereafter the stability and flow of the briquettes are determined according to Method C2 of SANS 3001-AS2. Indirect tensile strength, submersion index and creep property tests are carried out on the surplus briquettes;
- Record the test results on an appropriate data sheet and compare these against the required specifications;
- For coarse and medium slurry mixtures the same specifications as for asphalt mixtures should be applied;
- Once the optimum composition is determined, three sample mixtures are made up (allowing 10 litre less and 10 litre more than the optimum) and visually inspected for segregation, clotting and colour. Thereafter a thin layer of the slurry mixture is applied on card board and left so that the emulsion can break. Take note of the time it takes to break. Allow the mixture to harden. After a day or two the mixture can be tested with the heel of your shoe by making circular movements on it. Check the mixture for complete binder coverage of the aggregate as well as for segregation.

NOTES

1. 1200g slurry is usually too much to create a briquette 63 mm thick. Adjust the mass accordingly in order to end as close as possible to a thickness of 63 mm.
2. In the calculation of the laboratory mixture, a proportionate mixture for 1 m^3 of sand is used as a basis to compose 1200g laboratory samples.
3. After the consistency has been determined for the mixture that contains the least amount of emulsion, the water content of the other mixtures could be calculated by deducting the additional emulsion from the water content of the first mixture.
4. As a starting point, we can assume that the quantity of water that needs to be added to achieve workability is approximately 70-80% of the volume of the first emulsion.
5. It is sometimes necessary to make minor adjustments on site in order to optimise the mixture.
6. The percentage of net binder is calculated for control purposes. Slurry mixtures are allowed to break, then placed in an oven at 105-110°C and allowed to dry.
7. Binder extraction can be carried out by means of normal extraction methods (Method C7 of TMH1).
8. The accuracy of results depends mainly on the sampling process.

APPENDIX B

Determination of the consistency of a slurry mixture

This method describes the determination of the consistency of a slurry mixture by means of the flow cone test.

1 Definition

The consistency of a slurry mixture is defined as the amount of flow of the mixture over a flow plate, measured in millimetres.

The flow provides an indication of the effect of mix proportioning of the various constituents, as well as of the quantity of water in the mix, which determines its workability.

2 Apparatus

2.1 *Flow plate:* a 5 mm thick round metal plate with a diameter of 250 mm having a smooth surface which is resistant to chemical substances. A circle of 90 ±1 mm is engraved to a depth of between 0,5 and 0,8 mm in the centre of the plate. The width of the engraving is such that the cone (see 2.2) fits precisely into it. Concentric circles, at 10 mm diameter increments, are inscribed around the centre engraved circle outwards to the edge of the plate. The first circle after the centre circle is marked at 10 mm, followed by 20 mm, 30 mm etc.

The flow plate is mounted on a tripod, of which two of the legs are adjustable. A spirit level is mounted on the outer edge of the flow plate between the two adjustable legs.

2.2 A metal mould in the form of a frustum of a cone with the following internal dimensions: top diameter, 37,5 ±1 mm bottom diameter, 90 ±1 mm; height, 75 ±1 mm. The cone should be manufactured from a chemical-resistant metal with a thickness of between 0,8 and 1,5 mm.

2.3 A balance with a capacity of at least 6,0 kg and accurate to 0,1g.

2.4 A riffler with 13 mm openings, together with pans.

2.5 A thermostatically controlled oven capable of maintaining a temperature of 105 to 110°C.

2.6 A dispersing apparatus with a blade and container which should have a capacity of at least three times the volume of 3 kg of fine aggregate.

2.7 Mixing containers having a capacity of three times the volume of 500 g of fine aggregate.

2.8 Spatulas for mixing.

2.9 Measuring cylinders with capacities of 50 ml, 200 ml and 1 000 ml respectively.

2.10 A suitable organic solvent such as toluene.

3 Samples

3.1 *Aggregates*: approximately 15 kg of each type of aggregate is required. Carry out sieve analyses of each aggregate according to SANS 3001-AG1:2009[2].

3.2 *Mineral filler*: approximately 1 kg of each type of mineral filler is required. Cement or hydrated lime is normally used with anionic emulsions, while limestone dust, fly ash or silica fume is used with cationic emulsions.

3.3 *Emulsion:* the anionic or cationic emulsions should comply with the relevant SABS specifications[12].

3.4 *Water:* only potable water free of deleterious substances or chemicals should be used.

4 Method

4.1 Weigh out 3 or more 500 g samples of fine aggregate. If more than one type of aggregate is to be used, the various aggregates should be weighed out in the correct proportions in order to obtain total samples of 500 g each.

The type and quantity of mineral filler to be added depends on the type of emulsion to be used as well as on the grading of the fine aggregate. This, however, is normally in the order of 1 to 2 parts per 100 (by mass) of the fine aggregate.

The proportioning of the slurry mixture is therefore as follows:

Fine aggregate	100 parts	=	500 g
Cement	1,5 parts	=	7,5 g
Emulsion	20 parts	=	100 g

The quantity of water required to obtain the desired consistency of the slurry is determined as follows:

4.2 Add the calculated quantity of mineral filler to each of the 500 g portions of fine aggregate and mix the blend until a homogeneous colour is obtained. Add a small quantity of water to the first sample and mix it thoroughly. The calculated quantity of emulsion is now added to the mixture and mixed for 3 minutes. While continuing to mix, add additional quantities of water in small increments until a paste is formed i.e. until just before the mixture starts to flow. Record the total quantity of water added to the mixture.

Determine the flow of the slurry mixture as described in 4.3. Repeat the test on the second and third samples, but with higher water contents for each additional sample.

An alternative method for mixing in the water is as follows:

Add 9 parts water to the first sample and 12 and 15 parts to the second and the third samples respectively. After these have been thoroughly mixed, add the correct qualities of emulsion and continue mixing until a homogeneous mixture is achieved. Carry out the flow test on each sample.

4.3 *Flow test:* Place the cone on the previously levelled flow plate, ensuring that it is firmly seated in the engraved circular groove. Hold the cone firmly in place and fill the cone with the slurry mixture. Lift the cone carefully, allowing the slurry to flow across the plate. The degree of flow, i.e. the distance that the fine aggregate has dispersed, is measured where the greatest flow has occurred, and is reported as follows e.g. 10 – 20 mm. The flow of the other samples is determined in a similar manner.

4.4 *Laboratory control test:* After the quantity of water required to produce a slurry mixture with a specific workability has been determined, a control sample is made up. With the same proportions as those determined above, make up a 3000 g sample of slurry utilising a mechanical mixer.

It is important that most of the water, together with the mineral filler, is first mixed in with the fine aggregate prior to the addition of the emulsion. Use the remainder of the water to rinse out the measuring cylinder used for measuring out the emulsion, prior to adding it to the mixture.

The flow is then determined on the flow plate as described above.

4.5 *Field control:* Blend approximately 20 kg of the slurry mixture in a large basin or clean wheelbarrow, and determine the flow in a similar manner to that described in 4.3. This control test should be carried out on each batch of slurry produced.

5 Notes

5.1 A flow of 20-30 mm indicates that segregation of the fine aggregate should not occur.

5.2 The flow of a slurry to be applied in a thick layer, in order to eliminate surface unevenness, should be less than that indicated in 5.1.

5.3 If two layers of slurry are to be applied, the flow of the slurry for the second layer should be greater than that for the first.

5.4 Additional water is not required if application of the slurry takes place during hot windy conditions.

Determination of the stiffness of a slurry mix

Mix proportion	Aggregate:	100 parts
	Filler:	1: 1¼: 1½ or 2 parts
	Emulsion:	20 parts

Aggregate	Description	Source	Lab No.
* 6,7 mm aggregate			
* Crusher dust			
* Crusher dust/sand			

Mix proportions of aggregate

*6,7 mm aggregate : ________________ parts)
*Crusher dust : ________________ parts) – 100 parts
*Crusher dust/sand : ________________ parts)

(A) Mix proportions of material (500 g of aggregate)

	1	2	3	4	5	6
6,7 mm g/parts						
Crusher dust g/parts						
Crusher dust/sand g/parts						
Filler g/parts						
Emulsion g/parts						
Water ml/parts						
Flow (mm)						

(B) Control Test (3000 g aggregate)

*6,7 mm aggregate : ________________ parts = _______ g}
*Crusher dust : ________________ parts = _______ g}
*Crusher dust/sand : ________________ parts = _______ g}
*6,7 mm aggregate : ________________ parts = _______ g}
*Crusher dust : ________________ parts = _______ g}
*Crusher dust/sand : ________________ parts = _______ g}
Emulsion : ________________ parts = _______ g}
Water : ________________ parts = _______ g}
Flow : ________________ mm

Delete where not applicable

APPENDIX C

Binder condition of existing surfacing

Binder condition

Purpose

The purpose of rating the binder condition is to monitor the process of oxidation and hardening as this would decrease the flexibility of the surfacing and increase permeability. The information is used to determine the need for reseal or application of a rejuvenator/diluted emulsion.

For purposes of this manual (Sabita Manual 28), the binder condition (dry/brittleness) rating is used to select the appropriate slurry binder content from Figure 10.

Degree	Description	
	Stone seals	**Sand seals, slurry, asphalt**
1	Binder not fresh but still sticky, with bright black colour (no shrinkage cracks yet).	Mixture removed not pliable. Turn a screwdriver while applying force and take a small sample (no shrinkage cracks yet).
3	Binder is hard and brittle and appears dull (shrinkage cracks may have appeared).	Aggregate segregates from binder when sample is taken (shrinkage cracks may have appeared).
5	Binder is dull (brown) and very brittle (expect shrinkage cracks and/or aggregate loss).	Surfacing extremely hard (expect shrinkage/ravelling).

HINTS

The binder can be dry even if the surface in the wheel tracks appears to be fatty.

Surfacings with light coloured aggregate appear to be dryer than dark.

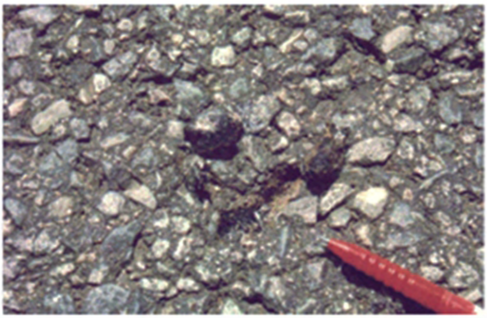
The colder the temperature, the more brittle the surfacing appears to be.

Use a screwdriver to remove aggregate or aggregate and binder for close inspection.

BINDER CONDITION

- **0**
- 1
- 2
- 3
- 4
- 5

- 0
- 1
- 2
- **3**
- 4
- 5



- 0
- 1
- 2
- 3
- 4
- **5**

Bleeding/fattiness

Description

Bleeding is the vertical upward movement of binder relative to the aggregate of the surfacing.

Purpose

Information is used to identify functional problems e.g. tackiness, to determine the appropriateness of maintenance treatments and to evaluate the appropriateness of the existing surfacing for the traffic and geometry of the road segment.

Description of degrees of bleeding

Degree	Description
1	Surfacing is slightly rich in excess binder. Aggregate well proud of binder.
3	Surfacing rich in excess binder. Smooth appearance, but aggregate visible in binder.
5	Surfacing very rich in excess binder giving the pavement surface a wet look. Film of binder covering all stones in wheel paths. Surface is tacky during hot weather, and/or wheel prints are visible in binder with possible pick-up of binder.

NOTE

Bleeding/fattiness is not necessarily considered a distress unless the surfacing becomes tacky.

BLEEDING/FATTINESS

0
1
2
3
4
5

0
1
2
3
4
5

0
1
2
3
4
5

NOTE

Slurry not appropriate on existing surfaces with bleeding/ fattiness of “Degree 4 or 5”.

APPENDIX D

Sampling and quality assurance

SAMPLING FOR DESIGN AND QUALITY ASSURANCE – SLURRY SEALS (From WCPA Materials Manual Table 8-60)					
Aspects to be Verified	**Type of Control**	**Sample Size**	**Sampling Frequency**	**Test Method**	**Remarks**
Aggregate Grading (also of blend)	Sieve Analysis, Fines Content, Dust Content	15 kg sand, 15 kg Crusher dust	5 Samples per source	TMH1 (B4)	Sand samples only if grading requires sand. Refer to project specifications w.r.t dense grading
Quantity of cement to be added	Aggregate grading with respect to the 0,075 mm fraction				
Slurry mix design	Mix proportions of aggregate, emulsion, cement, water	Aggregate from above and 5 litre emulsion & 5 litre of water to be used			
Consistency	Flow test			ASTM Consistency Flow Test	Refer to specification for criteria

QUALITY ASSURANCE: ACCEPTANCE OF MATERIALS FOR SLURRY SEALS (From WCPA Material Manual Table 8-59)

Component	Aspect to be Controlled	Type of Control	Sample Size	Sampling Frequency	Test Method	Remarks
Fine Aggregate: Crusher Dust	Grading	Sieve Analysis. Fines Content, Dust content	15kg	1 Sample per 1000 m³. Min. of 5 samples per source	SANS 3001-AG1	For the testing of deleterious materials, plastic bags should be used
	Deleterious Materials	Soluble salts			TMH1 (B16T)	
	Hardness (Crusher dust only)	Aggregate must come from an approved chips or base source			SANS 3001-AG1	
	Methyl Blue test to determine clay content					
Fine Aggregate: Sand	Grading	Sieve Analysis	15 kg	Sample per 1000 m³. Min. of 5 samples per source	SANS 3001-AG1	
	Atterber Limits	Liquid Limit, Plasticity index, Linear Shrinkage			SANS 3001-GR10	
	Deleterious Materials	Soluble Salts			TMH1 (B16T)	
Emulsion (Stable grade anionic)	SABS 309 Specification	SABS Mark	1 litre	1 Sample per batch		
Cement	SABS					
Water	Compatibility for dilution	Can Test	1 litre	1 per Source	Refer Section 3.2.5	If water is potable, then it will probably be suitable
	Inorganic impurities	pH Ca as $CaCO_3$, Total hardness	1 litre	1 per Source	SABS	

QUALITY ASSURANCE ON SITE (1) – SLURRY SEALS
(From WCPA Materials Manual Table 8-61)

Aspects to be verified	Type of Control	Sample Size	Sampling Frequency	Test Method	Remarks
Calibration of mass measuring device	Calibration certificate and use of test mass				
Permeability	Marvil test in Trial Section		Min of 6 samples per trail section	SANS 3001-BT12	Assess impact of proposed design grading and compaction strategy
Consistency	Flow Test	5kg	1 Sample per batch (i.e. delivered)	ASTM Consistency Flow Test	

QUALITY ASSURANCE ON SITE (2) – SLURRY SEALS (From WCPA Materials Manual Table 8-61)

Component	Aspects to be verified	Type of Control	Sample Size	Sampling Frequency	Test Method	Remarks
Emulsion	Viscosity		1 litre	1 Sample per batch (i.e. delivered)	Cationic: TMH1 (E8)(E16)	
Slurry mix	Grading & binder content	Extraction	0,5 kg	1/50 m^3 mix minimum 5 per day	SANS 3001-AG1 and SANS 3001-BT20	Test all samples on the first day to check conformance with specification. Thereafter test one sample daily on a random basis. Samples may be discarded after two months if permeability is acceptable and there are no visible surface defects
	Batch proportions	Batching by mass		Per batch		
	Workability	Flow Test		1/ batch ($5m^3$)	ASTM	
	Spread rate	Coverage kg aggregate/ m^2		Per batch		Continuous sampling by supervisor and random sampling by technician or engineer
Placing Efficiency	Permeability	Marvil Test		6 tests per km (minimum)	SANS 3001-BT12	