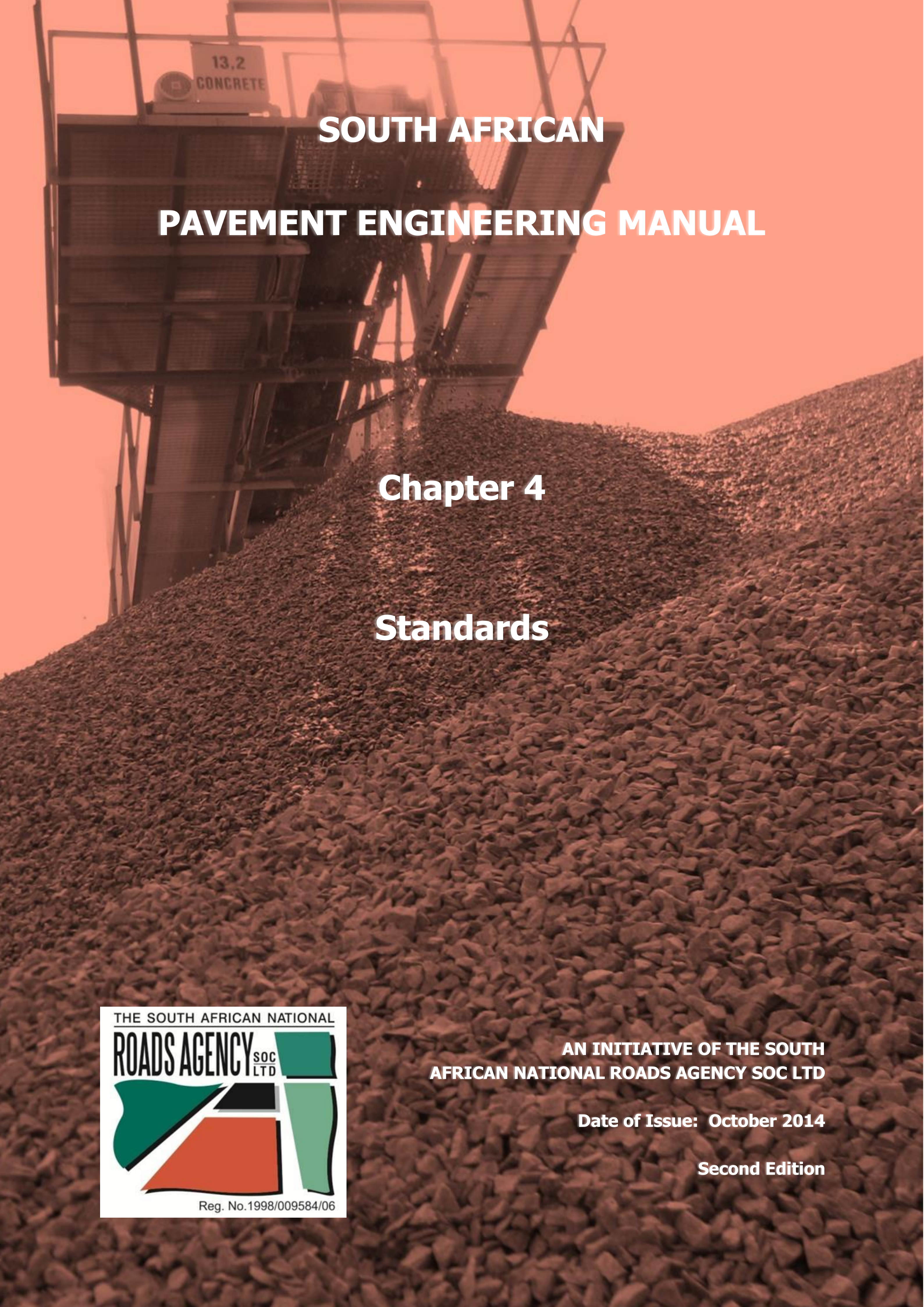

SOUTH AFRICAN

PAVEMENT ENGINEERING MANUAL

Chapter 4

Standards

THE SOUTH AFRICAN NATIONAL
ROADS AGENCY SOC LTD
Reg. No.1998/009584/06

AN INITIATIVE OF THE SOUTH AFRICAN NATIONAL ROADS AGENCY SOC LTD

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 4: Standards

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First edition published 2013
Second edition published 2014

Printed in the Republic of South Africa

SET: **ISBN 978-1-920611-00-2**
CHAPTER: **ISBN 978-1-920611-04-0**

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SCOPE

The South African Pavement Engineering Manual (SAPEM) is a reference manual for all aspects of pavement engineering. SAPEM is a best practice guide. There are many relevant manuals and guidelines available for pavement engineering, which SAPEM does not replace. Rather, SAPEM provides details on these references, and where necessary, provides guidelines on their appropriate use. Where a topic is adequately covered in another guideline, the reference is provided. SAPEM strives to provide explanations of the basic concepts and terminology used in pavement engineering, and provides background information to the concepts and theories commonly used. SAPEM is appropriate for use at National, Provincial and Municipal level, as well as in the Metros. SAPEM is a valuable education and training tool, and is recommended reading for all entry level engineers, technologists and technicians involved in the pavement engineering industry. SAPEM is also useful for practising engineers who would like to access the latest appropriate reference guideline.

SAPEM consists of 14 chapters covering all aspects of pavement engineering. A brief description of each chapter is given below to provide the context for this chapter, Chapter 4.

Chapter 1: **Introduction** discusses the application of this SAPEM manual, and the institutional responsibilities, statutory requirements, basic principles of roads, the road design life cycle, and planning and time scheduling for pavement engineering projects. A glossary of terms and abbreviations used in all the SAPEM chapters is included in Appendix A. A list of the major references and guidelines for pavement engineering is given in Appendix B.

Chapter 2: Pavement Composition and Behaviour includes typical pavement structures, material characteristics and pavement types, including both flexible and rigid pavements, and surfacings. Typical materials and pavement behaviour are explained. The development of pavement distress, and the functional performance of pavements are discussed. As an introduction, and background for reference with other chapters, the basic principles of mechanics of materials and material science are outlined.

Chapter 3: Materials Testing presents the tests used for all material types used in pavement structures. The tests are briefly described, and reference is made to the test number and where to obtain the full test method. Where possible and applicable, interesting observations or experiences with the tests are mentioned. Chapters 3 and 4 are complementary.

Chapter 4: Standards covers the standards used for the testing of various tests all material types used in pavement structures, including soils and gravels, aggregates, bituminous and cementitious materials, and waste/by-products and non-traditional chemical stabilizers. The majority of the standards come from TRH14 and the Standard Specifications. Where other standards are used, the sources are referenced and appropriate links provided. Where applicable, limits for the values obtained from laboratory test results are given. Guidelines are provided for mix and material compositions, and the suitability of materials for particular applications. Various material classification systems are provided, and Appendix A contains the TRH14 material classification. Chapters 3 and 4 are complementary.

Chapter 5: Laboratory Management covers laboratory quality management, testing personnel, test methods, and the testing environment and equipment. Quality assurance issues, and health, safety and the environment are also discussed.

Chapter 6: Road Prism and Pavement Investigation discusses all aspects of the road prism and pavement investigations, including legal and environmental requirements, materials testing, and reporting on the investigations. The road pavement investigations include discussions on the investigation stages, and field testing and sampling (both intrusively and non-intrusively), and the interpretation of the pavement investigations. Chapters 6 and 7 are complementary.

Chapter 7: Geotechnical Investigations and Design Considerations covers the investigations into fills, cuts, structures and tunnels, and includes discussion on geophysical methods, drilling and probing, and stability assessments. Guidelines for the reporting of the investigations are provided.

Chapter 8: Material Sources provides information for sourcing materials from project quarries and borrow pits, commercial materials sources and alternative sources. The legal and environmental requirements for sourcing materials are given. Alternative sources of potential pavement materials are discussed, including recycled pavement materials, construction and demolition waste, slag, fly ash and mine waste.

Chapter 9: Materials Utilisation and Design discusses materials in the roadbed, earthworks (including cuts and fills) and all the pavement layers, including soils and gravels, crushed stones, cementitious materials, primes, stone precoating fluids and tack coats, bituminous binders, bitumen stabilized materials, asphalt, spray seals and micro surfacings, concrete, proprietary and certified products and block paving. The mix designs of all materials are discussed.

Chapter 10: Pavement Design presents the philosophy of pavement design, methods of estimating design traffic and the pavement design process. Methods of structural capacity estimation for flexible, rigid and concrete block pavements are discussed.

Chapter 11: Documentation and Tendering covers the different forms of contracts typical for road pavement projects; the design, contract and tender documentation; the tender process; and the contract documentation from the tender award to the close-out of the Works.

Chapter 12: Construction Equipment and Method Guidelines presents the nature and requirements of construction equipment and different methods of construction. The construction of trial sections is also discussed. Chapters 12 and 13 are complementary, with Chapter 12 covering the proactive components of road construction, i.e., the method of construction. Chapter 13 covers the reactive components, i.e., checking the construction is done correctly.

Chapter 13: Quality Management includes acceptance control processes, and quality plans. All the pavement layers and the road prism are discussed. The documentation involved in quality management is also discussed, and where applicable, provided.

Chapter 14: Post-Construction incorporates the monitoring of pavements during the service life, the causes and mechanisms of distress, and the concepts of maintenance, rehabilitation and reconstruction.

FEEDBACK

SAPEM is a "living document". The first edition was made available in electronic format in January 2013, and a second edition in October 2014. Feedback from all interested parties in industry is appreciated, as this will keep SAPEM relevant.

To provide feedback on SAPEM, please email sapem@nra.co.za.

ACKNOWLEDGEMENTS

This compilation of this manual was funded by the South African National Road Agency SOC Limited (SANRAL). The project was coordinated on behalf of SANRAL by Kobus van der Walt and Steph Bredenhann. Professor Kim Jenkins, the SANRAL Chair in Pavement Engineering at Stellenbosch University, was the project manager. The Cement and Concrete Institute (C&CI) and Rubicon Solutions provided administrative support.

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- Jan Venter, Soilco

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1. INTRODUCTION

Chapter 4 covers the standards applied to the wide range of materials used in road pavements. This chapter is closely related to Chapter 3, which focuses on the tests carried out to ensure that the required standards are achieved.

Ideally, a standard should define what properties or characteristics of a material should be met when considering it as a component in a road pavement. Judged together with other criteria such as availability, costs-effectiveness and previous experience, material standards enable a comprehensive selection process to be followed.

> **Essential Reading on Pavement Materials**
>
> **TRH14:** Guidelines for Road construction Materials
>
> **Weinert:** The Natural Road Construction Materials of Southern Africa (1980)

In South Africa, surfaced pavements with several different types of bases are used, such as granular and asphalt bases, while some concrete roads are also constructed. The lower pavement layers are generally constructed using untreated natural gravels, while many types of gravel are modified or bound using cementitious products to improve their quality and functionality. Surfacings vary from thin surfacing seals to more substantial asphalt surfacings. It must be remembered that the largest number of kilometres that make up South Africa's road network are unsurfaced gravel roads. Gravel roads are not broadly covered in SAPEM. A good reference for the design of gravel roads is TRH20, Unsealed Roads: Design, Construction and Maintenance. Some materials requirements are, however, given in Section 2.9.

This chapter covers the applicable materials standards for the pavement types used in South Africa including:

- **Granular materials:** soils, gravels and aggregates
- **Bituminous materials:** bituminous binders, hot mix asphalt (HMA), cold mix asphalt, surfacing seals and bitumen stabilized materials (BSMs)
- **Cementitious materials:** concrete, concrete block paving, cementitiously stabilized materials
- **Waste** and **by-product** materials
- **Non-traditional chemical** stabilizers

Valuable information on materials is contained in Appendix A in TRH14, and in "The Natural Road Construction Materials of Southern Africa" (Weinert, 1980). These provide essential reading to gain a proper understanding of how the different rock types and their derivative gravels and soils are used in road construction in South Africa.

> **Standard Specifications**
>
> Note that when this chapter was written and updated, the 1998 version of the COLTO Standard Specifications was being used. However, these specifications are currently being reviewed. A revised version of the Standard Specifications is likely to be published in 2015 and is likely to be issued either by SANS or COTO.
>
> In this chapter, reference is only made to the Standard Specifications, which currently refers to the 1998 COLTO version.

1.1. Changes in Sieve Sizes

The testing of soils and gravels, aggregates, asphalt, bituminous materials, concrete and cement has until recently been carried out in accordance with the test methods given in TMH1. The translation of these test methods into SANS standards is well underway. See Appendix C of Chapter 3 for a complete list of the old and new tests numbers. Any differences between the old and new tests are briefly detailed.

As part of this update, sieve sizes have been reassessed, with the aim to:

- **Simplify**
- **Avoid radical changes**, except where necessary
- Follow **worldwide trends** trying to move to simple metric units
- Use **ISO 3310-1** 2004 (www.iso.org) approved sieve sizes
- Select sieve sizes that produce gradings with **reasonably distributed points**, remembering that the sizes are plotted on a log scale

Sieve sizes less than 1 mm remain unchanged, while the SANS sieve sizes of 1 mm and larger are shown in Table 1.

> **TMH1 to SANS Test Methods**
>
> The old TMH1 and new SANS test methods are listed in Chapter 3, Appendix C. Any differences between the methods are detailed.
>
> The new SANS test methods are available from the SABS webstore: www.sabs.co.za.

Table 1. Changes in Sieve Sizes

TMH 1 Sieve Size (mm)	SANS Sieve Size (mm)
75	75
63	63
53	**50**
37.5	37.5
26.5	**28**
19	**20**
13.2	**14**
9.5	**10**
6.7	**7.1**
4.75	**5**
2.36	**2**
1.18	**1**

Sieve Sizes

The new sieve sizes are used in this chapter.

As the SANS 3001 series of test methods are published they supersede the TMH1 methods. To permit a gradual change over, the SANS methods allow the new sieve sizes to be introduced over a period of time as the existing sieves become worn and are replaced.

2. STANDARDS FOR SOILS AND GRAVELS

2.1. Definition of Soils and Gravels

Soil can be defined as a material consisting of rock particles, sand, silt, and clay and is formed by the gradual disintegration or decomposition of rocks due to natural processes that include:

- **Disintegration** of rock due to stresses arising from expansion or contraction with temperature changes.
- **Weathering and decomposition** from chemical changes that occur when water, oxygen and carbon dioxide gradually combine with minerals within the rock formation, thus breaking it down to sand and clay.
- **Transportation** of soil materials by wind, water and ice to form different soil formations such as those found in river deltas, sand dunes and glacial deposits.
- **Temperature**, **rainfall** and **drainage** play important roles in the formation of soils as in the different climatic regions. Under different drainage regimes, different soils will be formed from the same original rock formation.

As these processes have been ongoing for millions of years, it becomes apparent that soils may bear very little resemblance to the original rock from which they were formed. In all likelihood they will consist of a mixture of materials from a variety of origins. It is also obvious that soils have a considerable variation in the degree of weathering and in the distribution of particle sizes or grading. These variations largely determine the quality of the soil in terms of its suitability for use as a road building material.

Materials that have a large proportion of fine material, in comparison to the proportion of coarser aggregate, are commonly referred to as "**soils**" in South Africa. Naturally occurring materials which are predominantly formed of coarser aggregate particles, and which have considerable strength due to aggregate interlock, with finer material occurring between the larger aggregate particles, are described as "**gravels**".

References for Gravel and Aggregate Layers

Gravels are covered in this manual in the following sections:

- Chapter 3: **Materials Testing**
  - Section 2, Tests on Soils and Gravels
  - Section 3, Tests on Aggregate
- Chapter 6: **Road Prism and Pavement Investigations**
  - Section 8, Materials Testing for Investigations
- Chapter 8: **Material Sources**
  - Section 2, Project Quarries and Borrow Pits
  - Section 3, Commercial Material Sources
- Chapter 9: **Materials Utilisation and Design**
  - Section 4, Pavement Layers: Soils and Gravels
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  - Section 3: Pavement Layers: Soils, Gravel and Aggregates
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2.2. Material Quality in the Pavement

The general rule in the construction of cost-effective flexible road pavements is to use the highest quality materials in the top layers of the pavement, where the highest stresses are imposed by the traffic's wheel loads, with a gradual decrease in material quality through the pavement. The poorest quality materials are used deeper in the pavement where the stresses are much reduced. In principle, the highest quality of material that is economically available should always be used. To ensure good "pavement balance" in flexible pavements, the decrease in material quality should be in approximately uniform steps.

Pavement Design

See Chapters 2 and 10 for further discussion on the design of flexible pavements and the location of materials in the pavement layer, and the associated pavement balance.

2.3. Material Classification Systems

Several different materials classification systems have been developed over the years. Some systems use the visual appearance of the material and results of various tests to make the classification more objective. The background and importance of the tests used in the classification systems are covered in Chapter 3. In South Africa, the TRH14 classification system is widely used. Other systems, such as AASHTO and Unified are in regular use elsewhere in the world but are less used in South Africa. These three methods are briefly discussed in the following sub-sections. Other classification systems include the ASTM Standard 2487 Soil Classification Chart and the classification system for design purposes in TG2, and discussed in Chapter 9: 15.

2.3.1. TRH14

In the TRH14 system, the untreated or granular materials are classified as:

- **Graded crushed stone:** G1, G2, G3
- **Natural gravels** (including modified and processed gravel): G4, G5, G6
- **Gravel-soil:** G7, G8, G9, G10
- **Waterbound macadam**: WM
- **Dump rock**: DR

The TRH14 requirements for G1 to G10 materials are summarised in tabular form in Appendix A of this Chapter.

TRH vs COLTO Material Requirements

Some requirements "G" category materials differ between TRH4 (1996), TRH14 (1985) and COLTO (1998). The TRH's are recommendations, while the COLTO document is the official specification. There are also differences between the COLTO specification and the SANS 1200 series, such as in SANS 1200 D: 1988 (Earthworks), and SANS 1200 M: 1996 (Roads General). The appropriate **Standards from the relevant documents should be applied , for the specification of a particular project.**

2.3.2. AASHTO

The AASHTO Soil Classification System was developed by the American Association of State Highway and Transportation Officials and is used as a guide for the selection of soils and soil-aggregate mixtures in the construction of roads (AASHTO M145-91, 2008; ASTM D3282, 2009). As shown in Table 2, materials are grouped into various primary and secondary classes. The primary classes range from A1 to A7. A1 class is well graded materials with low plasticity, suitable for use in the upper pavement layers. A7 class is very poor quality clayey materials that are unsuitable for road building purposes.

Table 2. AASHTO Soil Classification System

General Classification	Granular Materials (35% or less passing the 0.075 mm sieve)							Silt-Clay Materials (>35% passing the 0.075 mm sieve)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis (% passing)											
2 mm	50 max										
0.425 mm	30 max	50 max	51 min								
0.075 mm	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm											
Liquid Limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		NP	10 max	10 max	11 min	11 min	10 max	19 max	11 min	11 min[1]
Significant constituent materials	stone fragments gravel sand		fine sand	silty or clayey gravel sand				silty soils	clayey soils		
General rating as a subgrade	excellent to good							fair to poor			

Note:
1. Plasticity Index of A-7-5 subgroup is equal to or less that the liquid limit (LL) – 30. Plasticity Index of A-7-6 subgroup is greater than LL – 30.

2.3.3. Unified Soils Classification System (USCS)

Another soil classification system used in engineering and geology disciplines to describe the texture and grain size of soils is the Unified Soils Classification System (USCS) (ASTM D2487-06). This groups materials binomially according to their dominant particle size (gravel and sand or silt and clay) and the degree of particle sorting or plasticity respectively. An abbreviated version of this classification system is shown in Table 3 and Table 4.

Table 3. Unified Soils Classification System Definitions

First and/or Second Letter	Definition	Second Letter	Definition
G	gravel	**P**	poorly graded (uniform particle sizes)
S	sand	**W**	well graded (diversified particle sizes)
M	silt	**H**	high plasticity
C	clay	**L**	low plasticity
O	organic	**Pt**	Peat

Table 4. Unified Soils Classification System Details

Major Divisions			Group Symbol	Group name
Coarse grained soils: more than 50% retained on 0.075 mm sieve	Gravel: > 50% of coarse fraction retained on 5 mm sieve	clean gravel < 5% passes 0.075 mm sieve	**GW**	well graded gravel fine to coarse gravel
			GP	poorly graded gravel
		gravel with > 12% fines	**GM**	silty gravel
			GC	clayey gravel
	Sand: > 50% of coarse fraction passes 5 mm sieve	clean sand	**SW**	well graded sand
			SP	poorly graded sand
		sand with > 12% fines	**SM**	silty sand
			SC	clayey sand
Fine grained soils: more than 50% passes 0.075 mm sieve	Silt and clay: Liquid Limit < 50	inorganic	**ML**	Silt
			CL	Clay
		organic	**OR**	organic silt organic clay
	Silt and clay: Liquid Limit > 50	inorganic	**MH**	silt of high plasticity elastic silt
			CH	clay of high plasticity fat clay
		organic	**OH**	organic clay organic silt
Highly organic soils			**Pt**	peat

2.4. Standards for G4, G5, and G6 Quality Materials

Under the TRH14 classification system, G4, G5, and G6 quality materials are defined as consisting of **natural gravel or a mixture of natural gravel and boulders that may require crushing**. These materials may be modified by addition of small quantities of lime or cement, or by mechanical stabilization where other materials are added to adjust their grading and Atterberg Limits. The effectiveness of mechanical modification should be checked by monitoring the Atterberg Limits carried out on material passing the 0.075 mm sieve size.

> **Tests for G4, G5 and G6**
> The tests listed for natural gravel are discussed in Chapter 3: 2.

The following items regarding the TRH14 classification of natural gravels, which is summarized in Appendix A, should be noted:

- **G4** quality materials are required to fall within a **grading** envelope. G5 and G6 gravels have only a maximum size, or maximum of two thirds of the compacted layer thickness, and a grading modulus requirement.
- **G5 and G6** natural gravels are subject to minimum **grading modulus** criteria, which also affect the maximum Plasticity Index (PI)

> **Atterberg Limits for G4s in Bases**
> If a high plasticity problem develops, consider modifying with a low percentage of hydrated lime, or alternatively by admixing a non-plastic finely graded natural binder. Refer to Chapter 9: 6.2 for more details.

requirement for these materials.

- Besides the minimum **CBR** requirement, there is also a maximum CBR swell requirement for G4, G5, and G6 quality gravels.
- For **G5 quality materials** that are used in the dry parts of the country, the minimum CBR at 95% modified AASHTO compaction may be reduced from 45 to 25. This reduction in CBR is only applicable where the natural gravel is used as a subbase under at least 150 mm of base, in pavements carrying very light traffic.

> **G4 Gradings**
> Some Road Authorities may elect to include additional constraints, such as a grading requirement, when a crushed product is specified.

More stringent standards for G4, G5, and G6 quality materials are set in the Standard Specifications. Notable items in the Standard Specifications requirements for these materials that differ from those in TRH14 are:

- **Durability:** "Durability Mill Index" (DMI) requirements for G4 quality material, with maximum limits for various types of rock. The quality of G5 and G6 mudrock materials is also governed by wet 10% FACT values, as well as by the "Venter test" classification.
- **Atterberg limits:** Requirements for G4 and G5 quality calcretes are included, where there is some relaxation in the standards compared with those of other materials. This is primarily brought about by the unusual characteristics of calcretes and the potential for some self-cementation.
- **Plasticity Index and linear shrinkage**: TRH14 stipulates a maximum Plasticity Index (PI) of 12, or a value equal to 3 times the grading modulus plus 10 for G6 quality materials. The Standard Specifications requires a maximum PI of 12, or a value equal to 2 times the grading modulus plus 10. The Standard Specifications also specifies a maximum linear shrinkage of 5%, and gives specific Atterberg Limit requirements for calcretes. TRH4 permits a maximum PI of 15 for calcretes, provided the linear shrinkage does not exceed 6%.
- **Soluble salts:** Standards for soluble salts (see Section 2.7), similar to those for G1, G2, and G3 crushed rock quality materials, are specified.
- **Flakiness Index:** A maximum Flakiness Index for G4 quality materials is specified. See Chapter 3: 3.2.2 for a description of flakiness and fractured faces.

> **Repeatability of CBR Tests**
> The CBR of a material is an indirect measure of shear strength or bearing capacity under a single load. Due to differing properties in natural materials (grading, plasticity), even on a split sample, significant variations can occur in CBR values. In general, the higher the strength, the greater the variability. In applying CBR standards for a material these should never be based on a single value. Wherever possible at least three values should be obtained.

- **Fractured faces:** There is a requirement regarding fractured faces of both G4 and G5 quality materials derived from the crushing of alluvial gravels.
- **Grading envelopes**: Whereas only one grading envelope for G4 quality materials is presented in TRH14, The Standard Specifications specifies a grading envelope for uncrushed G4 gravel, as well as two grading envelopes for crushed materials, with different maximum aggregate sizes. Note that the SANS specifications do not provide for these different grading envelopes and a project specification is required.

Other items that should be noted regarding G4, G5, and G6 materials are:

- The presence of **excessive deleterious minerals**, such as mica and sulphide minerals, may affect the durability of these materials.
- There may be benefit in **blending material sources** to obtain a suitable end product.
- Certain changes in requirements that apply specifically to **calcretes** are covered in Appendix A of TRH14.
- **Two-stage crushing** of some gravels, particularly blocky, partly weathered dolerites, as well as alluvial and colluvial materials, should be considered to achieve the required product.

> **Materials to be Stabilized with Cement**
> Both the TRH14 and the Standard Specifications require materials to be of **minimum G6 quality** before stabilization to achieve C3 and C4 quality after stabilization. However some Road Authorities specify minimum G5 quality material to attain C3 quality after stabilization.

2.4.1. Effect of Traffic on Placement of G4, G5 and G6 Layers in a Pavement

The use of these materials in the pavement structure depends on the level of traffic that the road is designed to carry. For instance, on lightly trafficked roads G4 and G5 quality natural gravels may be used in the base layer. For heavier trafficked roads, these materials would only be suitable for use in the subbase layer or lower down in the pavement structure.

When it comes to pavement designs for heavy traffic, it is usual to stabilize the subbase layer using cementitious stabilizing agents, and materials of at least G5 or G6 standard are selected for this purpose. Details of the standards applicable to cementitiously stabilized materials are covered in Section 5.3.2.

2.5. Standards for G7, G8, G9 Quality Materials

G7, G8 and G9 quality materials are **naturally occurring gravels and soils** and are normally used in the lower layers of the pavement or in the subgrade. Typically G7 quality materials are used in the upper selected layer, G8 and G9 in the lower selected layer, while G10 quality material is reserved for use in earthworks. Where better quality materials are economically available they should, however, be used in preference to G10 quality materials in the earthworks.

In TRH14, the requirements for G7 materials include:

- Maximum **particle size** not greater than two thirds of the compacted layer thickness
- Minimum **Grading Modulus** of 0.75
- Maximum **Plasticity Index** of 12 or 3 times the grading modulus plus 10
- Minimum **CBR** value of 15 at 93% MDD
- Maximum **CBR swell** of 1.5% at 100% MDD

The quality of the G7, G8, and G9 is controlled by CBR and swell values.

Classifying Materials

It is necessary to take all requirements into account when classifying and deciding upon the suitability of soils and gravels for use in a particular layer in the pavement structure.

The Standard Specifications specifies the requirements of G7, G8, and G9. These requirements are more stringent than those recommended in TRH14:

- Nominal **maximum size**
- **Durability** of mudrocks
- **Grading modulus** limits for G8 and G9 materials
- **Soluble salt** contents

2.6. Standards for G10 Quality Materials

The lowest quality of material generally used in road construction is G10, where it may be used in the construction of fills. In TRH14, the quality of G10 soils is governed by a minimum CBR of 3% at in situ density (usually minimum 90% MDD), as well as by a maximum CBR swell of 1.5%.

The Standard Specifications do not specifically require a minimum G10 quality material for use in fills, but specifies a minimum CBR value of 3% at 90% MDD when the material is situated within 1.2 metres of the final road level. Some road authorities specify a maximum swell at 100% MDD of not more than 2%.

A minimum CBR of 3% at 100% MDD is specified in the case of materials being placed within 1.2 m to 9 m of the final road level, subject to the requirements specified in the project specifications. The quality of material in fills deeper than 9 metres is also subject to the project specifications.

2.7. Deleterious Materials

Three different types of deleterious substances that can affect the quality of soils and gravels are covered in TRH14:

- Sulphide minerals
- Soluble salts
- Mica

Sulphide minerals are only likely to pertain to crushed rock (mostly mine waste), but soluble salts could cause long-term problems with natural gravels. Guidelines are given regarding acceptable limits for electrical conductivity tests carried out on the fines.

Drainage

Drainage is an extremely important consideration for pavements! Water is the primary cause of premature failure, accelerated distress and reduced structural capacity.

All aspects of drainage are comprehensively covered in SANRAL's Drainage Manual and not repeated in SAPEM. Download the Drainage Manual from www.nra.co.za.

The Standard Specifications give limits for electrical conductivity and imposes additional limitations on the use of materials with a pH of less than 6.

TRH14 gives similar recommendations for deleterious materials for G7 quality materials as for G4, G5 and G6 materials. The requirements in the Standard Specifications cover G7, G8, and G9 quality materials.

It is important to note that construction materials that may contain deleterious minerals can often be used if an adequate understanding of the problem is developed and appropriate remedial actions or precautions are taken. Experts in the respective problem materials should be consulted to assist with these decisions.

2.8. Compaction of Soils and Gravels

The process of compaction, a form of mechanical stabilization resulting in densification of the material, is key to ensure the best possible performance of a gravel or soil. Compaction of soils and gravels is measured relative to the MDD (maximum dry density) determined in the laboratory. The intention should always be to aim for the highest practical densification achieved with an effort commensurate with the type of equipment being used and the intended usage of the road. However, beware of gravels with softer aggregates, often indicated by low CBR values at the 100% MDD effort or low 10% FACT values. In this case, 'over-compaction' results in crushing of the coarser aggregate and the generation of excess fines, which often makes the material unsuitable for use or can even lead to de-densification.

MDD / Mod

MDD (SANS 3001-GR30) should be used to replace terms previously used such as **Modified AASHTO density** or "**Mod**".

The minimum levels of compaction for soils and gravels are generally specified in terms of percentage MDD in TRH14 (using Modified AASHTO) and the Standard Specifications. However, some road authorities specify compaction of G4 quality material used as base in terms of bulk relative density.

2.8.1. Compaction Requirements for Different Layers and Traffic Levels

For subbase layers, a minimum of 95% MDD for natural gravels is given in TRH14. The minimum levels of compaction required for the selected layer and the subgrade are 93% and 90% MDD respectively.

On roads carrying low traffic levels, where G4 materials are used in the base layer, the requirement varies between a minimum of 98% and 100% MDD, while some road authorities specify a minimum of 86% of bulk density. See Chapter 3: 2.6 for definitions of the various types of density measures.

See Section 2.8.3 for the compaction of sands.

The Standard Specifications specifies similar minimum compaction criteria for selected and subbase layers, but includes an option for higher levels of compaction to be included in the project specification.

2.8.2. Trial Sections

Sometimes conditions exist where density tests do not give consistent or reliable values. In such cases, a trial section should be constructed. Various combinations of compaction equipment, moisture content, mixing and number of passes should be investigated to determine the best combination to achieve maximum densification. Apart from using some measure of density or shear strength test, the material should, on excavation, appear solid and dense. Where density tests continue to be unreliable, a method specification based on the trials should be used to control compaction.

In recent years, compaction equipment in general use for major road construction has become increasingly sophisticated, heavier and more effective, resulting in the relatively easy achievement of high relative compactions. In the case of lightly trafficked roads where smaller compaction equipment is used, or with labour intensive projects, lower standards may be used. This is, however, not the case where hand patch repairs are carried out on major roads, and the higher standards should be maintained, possibly by compacting in thinner layers. Various authorities have predetermined compaction standards, but as a guide the minimums in Table 5 are recommended. While crushed stone (G1 to G3) is generally used on higher traffic roads, good quality ferricrete and calcrete have been used successfully up to ES3 (1 – 3 MESA) traffic, particularly in dry areas.

De-densification

Be careful of compacting gravels that have softer aggregates (low CBR or low 10% FACT values). Over-compaction can lead to crushing and excess generation of fines, and ultimately de-densification.

Table 5. Minimum Relative Compaction by Traffic Class

Category	Base		Subbase	
	Minimum Relative Compaction by Traffic Class (% of MDD)			
	> ES1[1]	ES1[2]	> ES1[1]	ES1[2]
G4	102	100	–	–
G5	–	98	97	95
G6	–	–	–	95

Notes
1. >1 MESA
2. 0.3 – 1 MESA

Densification of the lower layers is also important for the performance of the material. Because of the reduced quality of the material, such as higher PI and poorer grading, the high compactions required for base and subbase are not always practical. As a result, lower relative compactions have been specified for the lower pavement layers. Various authorities have predetermined compaction standards, but as a guide, the following are recommended for G7 to G9 materials:

- **Selected layer** or upper **selected subgrade** (SSG) layer a minimum of 95% MDD.
- **Lower SSG** layer a minimum of 93% MDD.
- Compact **sand** to 100% MDD, as per the Standard Specifications for fill and selected layer for uniform sands.

2.8.3. Sands

Sands may be used in the lower pavement layers and are defined as:

- **Non-plastic materials** with not less than 95% finer than 5 mm
- A minimum of **50% passing 0.425 mm**
- A maximum of **20% passing 0.075 mm**

TRH14 recommends a minimum compaction of 100% MDD for sands. The Standard Specifications specify a lower minimum level of compaction of 95% MDD where sands have more than 20% passing the 0.075 mm sieve.

Compaction of Sands

Where the percent passing 0.075 mm is between 10 and 20%, trials should be performed to set an appropriate minimum compaction, typically 100% MDD.

The reason for the higher compaction requirement is that clean non-plastic uniform sands compact readily to at least 95% MDD with very little effort, but still have large void ratios and thus tend to densify under traffic if placed at lower densities. They can also have unexpectedly high strengths when highly compacted and confined. Extensive experience indicates that where the material passing 0.075 mm exceeds 10%, it may be difficult to achieve 100% MDD. It is recommended that where the material passing 0.075 mm lies between 10% and 20%, compaction trials should be carried out using conventional equipment and an appropriate minimum relative compaction be set between 95% MDD and 100% MDD, based on the density results obtained in the trials. Excessive compaction of sandy materials could result in crushing of particles, does not achieve 100% MDD, and leads to unnecessary disputes and delays.

Compacting Sandy Materials

Excessive compaction of sandy materials could result in crushing of particles, does not achieve 100% MDD and leads to unnecessary disputes and delays.

The compaction of non-cohesive sands can be difficult as the sand shoves under the rollers. In these cases, the layer should be dumped slightly wider than required to provide some constraint at the edges. The "boxed-in" effect allows for better compaction.

2.9. Standards for Gravel Wearing Course

Gravel, or unpaved roads, form a major part of the road network in South Africa. Careful selection of gravel for wearing courses is essential to improve the performance of these roads and to reduce maintenance costs.

In considering the standards required for gravel wearing courses, a number of factors are listed in TRH20 that should to be considered to provide good performance:

- **Dust:** The levels of dust produced by vehicles traveling along the road should be reduced as far as possible. Dust has an adverse effect on safety and comfort and also increases vehicle operating costs. It also decreases the value of crops alongside the road and increases air pollution. Excessive dust is an indication that material from the wearing course is being lost, and will have to be replaced. Dust is a loss of fine material, which makes the remaining coarser material rougher and less suitable as a wearing course.

- **Potholes:** Potholes cause a large increase in roughness, with a corresponding escalation in vehicle operating costs. Potholes are also a safety risk. The quality and strength of the wearing course should be uniform and should be able to maintain a good surface profile so that rainwater does not pond and lead to the formation of potholes. Pothole repairs are costly and significantly increase maintenance costs of gravel roads.
- **Stoniness:** Materials containing high proportions of large rock particles produce excessively rough roads, increasing the maintenance costs of vehicular traffic and road maintenance equipment. Sharp stones can damage tyres and affect road safety.
- **Corrugations:** Gravel wearing course should be selected with properties that do not corrugate under traffic. Corrugations cause roughness and reduced vehicle stability that adversely affects road safety.
- **Ruts:** Ruts are either caused by differential compaction by traffic or by gravel loss in the wheel tracks. This leads to water ponding and the formation of potholes. Ruts also reduce comfort and safety.
- **Ravelling:** Ravelling is the term given to the generation of loose material on the road surface by the passing traffic. This adversely affects safety and comfort, and results in gravel loss and the danger of loose stones damaging windscreens.
- **Slipperiness:** The wearing course should not be too slippery when wet as this adversely affects road safety and the speed at which vehicles are able to travel safely along the road.

The propensity of gravels to show the properties listed above can be obtained by carrying out grading and linear shrinkage tests. The results, when expressed as the shrinkage product and grading coefficient can be plotted on Figure 1 to assess their suitability as wearing courses for unpaved roads, as well as any potential problems that are likely to dominate their performance. It is essential that all grading analyses are normalized to 100% passing the 38 mm sieve.

TRH20 recommends gravel for the wearing course of unpaved roads that meets criteria based on:

- Maximum **particle size**
- **Oversize** index
- **Shrinkage product**
- **Grading coefficient**
- **California Bearing Ratio** (CBR)

Different limits for these parameters are recommended for rural and urban roads, as well as for haul roads. These details are available in TRH20.

Grading Coefficient and Shrinkage Product

Grading coefficient:

$$G_C = \frac{[(P28 - P2.0) \cdot P5]}{100}$$

Shrinkage product:

$$S_p = BLS \cdot P0.425$$

Where:
P28 = percent passing 28 mm sieve
P5 = percent passing 5 mm sieve
P2 = percent passing 2.0 mm sieve
P0.425 = percent passing 0.425 mm sieve
BLS = bar linear shrinkage from liquid limit

To use Figure 1, the gradings must be normalised. This is carried out by dividing the percentage passing each of the fractions by that passing the 37.5 mm screen, and multiplying by 100. This has the effect of proportionally increasing the percentage passing each fraction by the quantity retained on the 37.5 mm screen.

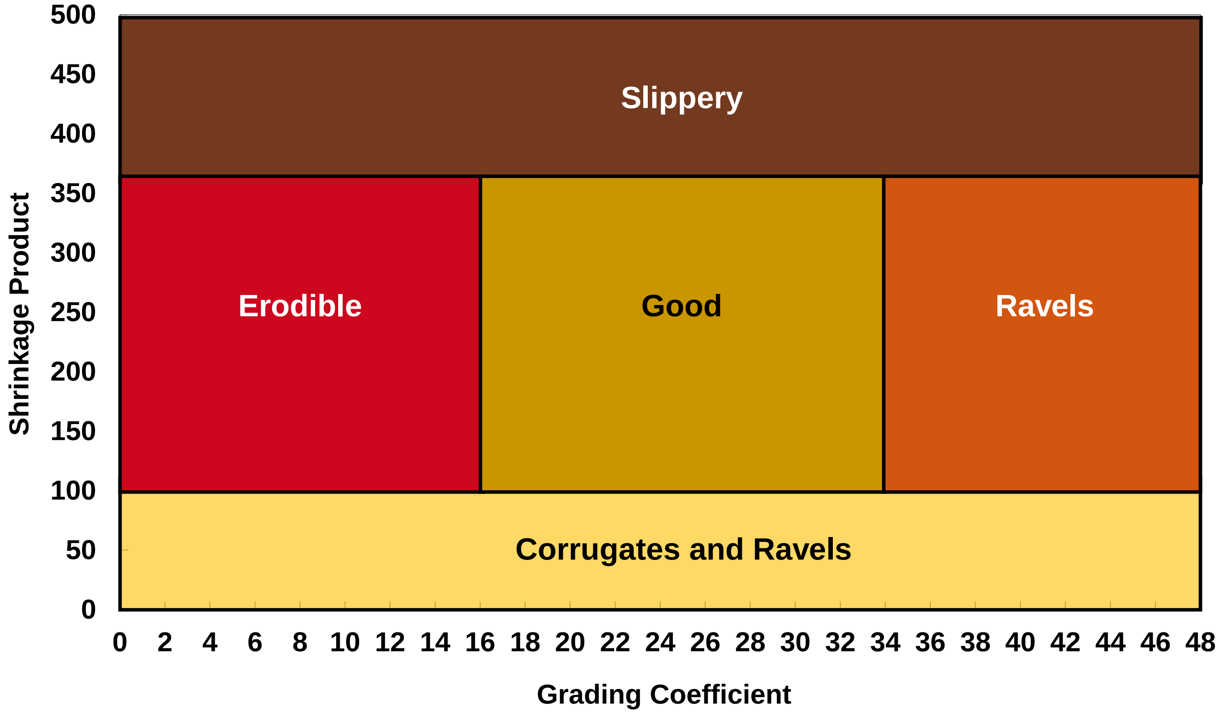


Figure 1. Relationship Between Shrinkage Product, Grading Coefficient and Performance of Gravel Wearing Course Gravels

3. STANDARDS FOR AGGREGATES

3.1. Definition of Aggregates

There are a number of formal definitions of **aggregate**; one describes aggregate as "a composition of minerals separable by mechanical means". In road building terms, aggregate consists of hard material which is generally derived from the crushing of solid rock or boulders. Aggregate may also be obtained by crushing slags, such as those produced in the manufacture of steel, ferrochrome and ferromanganese, from mine waste dumps or from certain combustion ashes.

3.2. Uses of Aggregates as Road Building Materials

Aggregates are used in a number of areas in road building, such as:

- **Granular base** and subbase layers
- **Asphalt** mixes
- Surfacing **seals**
- **Concrete** in rigid pavements and in all kinds of structures

Besides these applications, large aggregate fragments, known as "dump rock", are used to bridge poor subgrades. Smaller single-sized particles are used in applications such as subsoil drains and drainage layers.

3.3. Common Rock Types

Compared with many other countries, South Africa has a plentiful supply of hard rock, which can be obtained either by quarrying naturally occurring deposits of hard rock, or by utilising the rock from mine dumps. Use of mine dump rock is a significantly more sustainable or "green" practice.

A useful classification of the different rock types used in road construction is given in Appendix A of TRH14, where rocks are classified into various groups based on their engineering geological characteristics. Some of the rock types most commonly crushed and used as aggregates in road construction in South Africa are illustrated in Figure 2 and summarised in Table 6. Chapter 8 contains more information on common rock types, quarries and borrow pits.

3.4. Aggregate Quality

The standards for aggregates used in various applications in road construction obviously differ quite considerably, depending on the most important properties required by each application. The most important properties for various applications are summarised in Table 7.

Many of these properties are more a function of the mining, crushing and screening process than of the natural properties of the material. Deficiencies can, thus, usually be rectified by adjusting the manufacturing process.

Standards for Aggregates in Surfacings

Standards for aggregates in asphalt as well as in spray seals and micro-surfacings are included in Section 4 and for concrete in Section 5.1.

Figure 2. Common Rock Types

Table 6. Common Rock Types for the Production of Aggregates

Rock Group	Most Widely Used Types	Comments
Basic crystalline	• Dolerite • Gabbro • Norite • Basalt	• **Dolerite** is a basic igneous rock, found as intrusions in the form of dykes and sills in many parts of the country. Extensively crushed for use in road construction. • **Gabbro** and **Norite** are found mostly in Limpopo and North West Provinces. Extensively crushed for use in aggregates for road construction. • **Basalt** is widespread over the central, northern and eastern parts of the country. • Caution should be exercised when using basic crystalline materials, due to variable properties, possible **rapid degradation** and **high shrinkage** in concrete.
Acid crystalline	• Granite/gneiss	• **Granite/gneiss** occurrence is widespread. Usually satisfactory for use after crushing in granular base and subbase, as well as in concrete. • Granite's **glassy texture** can cause bitumen adhesion problems. • Some granites may have high **mica** contents.
High silica	• Hornfels • Quartzite	• **Hornfels** is extensively crushed and used in road construction in the Western Cape. • **Quartzite** results from the re-crystallization of sandstone under great pressure, improving its qualities as an aggregate for use in road construction. Deposits of quartzite are widespread and the rock is utilised extensively as road building aggregate. • Quartzite's **glassy texture** can cause bitumen adhesion problems.
Diamictites	• Tillite	• **Tillite** was formed from glacial debris and therefore consists of a variety of rock types, bonded together in a clayey matrix. Its quality is therefore variable. • **Used fairly extensively** as an aggregate in the construction of roads in the Province of Kwazulu-Natal and in the southern Cape.

3.5. Standards for Aggregates Used in Granular Bases

As mentioned in Section 2.3, the materials classification system presented in TRH14 is generally used in South Africa.

The materials used in the three types of granular bases, G1, G2, and G3, which consist of well-graded crushed stone, are considered as aggregates in terms of the definition given in Section 3.1, rather than as gravels or soils. However, they are tested using gravel test methods for grading and plasticity, and aggregate test methods for strength and relative compaction.

With reference to TRH4, note that G4 quality material, which is covered under Section 2.4 of this chapter as natural gravel, is also suitable for use in the base layer of moderately trafficked roads, especially in the dry regions of the country.

Materials used to construct waterbound macadam-type pavements, which comprise fairly large single-sized crushed stone fragments, with finely graded crusher dust being used to fill the voids between the larger particles, can also be described as aggregates. Standards applicable to these materials are covered in Section 3.5.2.

TRH14 Classification System

The requirements for all the material classes included in this system are given in Appendix A.

Table 7. Aggregate Properties Required for Various Applications

Property	Granular base	Subsoil drains	Asphalt	Spray seals	Micro-surfacings	Rolled in chips	Concrete
Grading	✓	✓	✓	✓	✓	✓	✓
Atterberg Limits	✓						
Flakiness	✓		✓	✓		✓	✓
ACV	✓	✓	✓	✓	✓	✓	✓
10% FACT	✓		✓	✓		✓	✓
Deleterious materials	✓		✓	✓			✓
Fractured faces	✓	✓	✓	✓		✓	✓
Durability	✓	✓	✓	✓		✓	
Polished stone value			✓		✓	✓	
Sand equivalent			✓		✓		
Water absorption	✓		✓				✓
Bitumen adhesion			✓				
Bitumen absorption			✓				
Siliceous content							✓
Chloride content							✓
Alkali reactivity							✓
Water demand							✓
Drying shrinkage and wetting expansion							✓
Abrasion resistance							✓

3.5.1. Standards for G1, G2, and G3 Quality Materials

Base materials are classified into the three different classes according to their fundamental properties. The requirements for each class refer to their in situ properties after compaction.

The specifications for each of the three classes of granular base are described in the Standard Specifications. The requirements for the source materials are:

- **G1 quality material** must be produced from sound rock, clean, sound mine dump rock, or clean, sound boulders. Only fines from the same sound parent material may be added to achieve the required grading.
- **G2 and G3 quality materials** specifications are slightly more lenient, and allow the use of coarse gravel as a parent material, as well as the additional of non-parent fines.

The most important properties of the three classes of granular base are discussed in the following sub-sections.

3.5.1.1. Atterberg Limits

The plasticity of fines produced during crushing or added to G1, G2, and G3 materials, as well as the Atterberg Limits of the final product, are strictly controlled, as summarised in Table 8.

Table 8. Atterberg Limit Criteria for G1 to G3 Aggregates

G1	
Liquid Limit	• Any individual measurement shall not exceed 25%.
Plasticity Index	• Any individual measurement shall not exceed 5. • The arithmetic mean of the PI's for a lot (minimum 6 tests) shall not exceed 4. • If the PI of the fraction passing the 0.075 mm sieve is more than 12, chemical modification is required. After chemical modification, the PI of the fraction passing the 0.075 mm sieve shall not exceed 8. Chemical modification to reduce the PI should only be done with caution and after careful consideration.
Bar Linear Shrinkage	• Shall not exceed 2 %.
G2	
Liquid Limit	• Any individual measurement shall not exceed 25%.
Plasticity Index	• Any individual measurement shall not exceed 6. • The arithmetic mean of the results determined for the lot (minimum 6 tests carried out from the same source having the same approved treatment), shall not exceed 4.5. Each sample shall represent a quantity of material not exceeding 200 m^3. • If the PI of the fraction passing the 0.075 mm sieve is more than 12, chemical modification is required. After chemical modification the PI of the fraction passing the 0.075 mm sieve shall not exceed 8. Chemical modification to reduce the PI should only be done with caution and after careful consideration.
Bar Linear Shrinkage	• Shall not exceed 3%.
G3	
Liquid Limit	• Any individual measurement shall not exceed 25%
Plasticity Index	• Any individual measurement shall not exceed 6. • If chemical modification is required, then the PI of the material passing the 0.075 mm sieve shall not be more than 10.
Bar Linear Shrinkage	• Shall not exceed 3%.
Calcrete	The plasticity criteria for calcrete differs from that of other materials, based on the fact that the plasticity of pedogenic material is related to the fineness of the carbonate or iron hydroxide particles and probably also by a degree of porosity. The porosity is particularly marked in calcretes which can have an appreciable amount of diatom skeletons, which are hollow silicate skeletons of microfossils (algae). The water in these pores, which has little effect on the properties of the material, is also expelled in the oven and thus adds to any quantity of water measured in the test. The result is that both the liquid limit (LL) and Plastic Limit (PL) tend to rise, the liquid limit more than the plastic limit, with a consequent increase in the Plasticity Index (PI), hence the PI criteria can be relaxed slightly. • PI shall not exceed 8%. • The product of the percentage passing the 0.425 mm sieve and the bar linear shrinkage (LS) shall be equal to or less than 170.

3.5.1.2. Modification

If chemical modification is required, then the PI of the material passing the 0.075 mm sieve shall not be more than 10 after modification.

The need to address the PI of the minus fraction, as well as the usual 0.425 mm fraction, stems from the practice of adding natural sand to counter PI problems with the minus 0.425 mm fraction. During the period that the material is stockpiled, or as it is being processed on the road, the sand washes out and the PI problem returns.

In materials from certain quarries that had not experienced PI problems based on the minus 0.425 mm fraction alone, it was found that the PI of the minus 0.075 mm fraction did not comply, which mandates chemical modification. This is typically done by adding hydrated lime, using a minimum of 1.0% by mass, to ensure uniform distribution in the pavement layer.

PI Criteria for Calcretes

The plasticity criteria for calcrete differs from that of other materials due to its porous structure.

Reducing the PI of G1 and G2 Materials

Modification to reduce the PI of G1 and G2 materials by adding natural sand should only be done with caution and after careful consideration.

This potential PI problem can be traced back to the origin of the rock types and the rock forming minerals. For example, crushed stone bases manufactured from hornfels, some basic crystalline rocks and argillaceous sandstones are prone to high PI's in their 0.075 mm fractions and respond well to treatment with lime. Karoo sandstones with initially acceptable PI values are known to break down under traffic after construction, generating more fines. The Durability Mill Index test (Chapter 3: 2.9) can be used to identify problem materials.

3.5.1.3. Strength

Strength requirements are specified in terms of both:

- **10% Fine Aggregate Crushing Test** (10% FACT), both dry and soaked
- **Aggregate Crushing Value** (ACV)

The limits are dependent on the type of parent rock. The Standard Specifications stipulate that argillaceous rock may only be used if specified in the project specifications, or with the engineer's written approval.

There is a direct correlation between the 10% FACT and ACV for materials that have either a minimum 10% FACT value of 150 kN (dry), or alternatively, have a maximum ACV value of 25. It is not necessary to specify both test requirements.

3.5.1.4. Deleterious Materials

Deleterious materials, such as weathered rock, mica, clay and sulphide minerals, may adversely affect the durability of the aggregate. This may be reflected by low 10% FACT values or by a low wet/dry ratio. In this case, further examination of the mineral composition under a microscope should be undertaken. Any visible presence of mica (particularly muscovite, as biotite has seldom caused any problems) should be investigated as this may adversely affect the compaction of the base layer. For G1 and G2 high quality crushed stone bases, it is recommended that the dry 10% FACT values should not be less than 180 kN. These are discussed more in Chapter 8: 3.5.

3.5.1.5. Durability

The durability of the Basic Crystalline group of rocks should be checked using an ethylene glycol soak test. This test shows whether the rock is prone to rapid weathering after exposure to the atmosphere, as may occur when smectite clay minerals are present in micro-fissures in the rock.

Both the Standard Specifications and TRH14 specify indirect requirements for durability in terms of the ACV or 10% FACT requirements. If the 10% FACT value is very high (often > 300 kN), and the soaked value is more than the specified dry limit for that material (the soaked to dry ratio may be less than 75%), the material can be considered for use, provided that DMI testing is done and the results comply with the Standard Specifications for gravels.

3.5.1.6. Soluble Salts

The possible presence of soluble salts is assessed using pH and electrical conductivity tests. Where the electrical conductivity (EC) of the minus 7.1 mm fraction is equal to or less than 0.15 Siemens per metre (S/m), the material may be used. Where the EC is greater than 0.15 S/m and the pH is less than 6, the material should be treated with lime until the pH is equal to or greater than 10. The material may then be used. Any later decrease in the pH should be ignored as long as it remains above 8.

The Standard Specifications also covers requirements for Witwatersrand Quartzite, as either crushed stone or mine sand. Where the pH is less than 6, the material is treated with lime until its pH is equal to or greater than 10. The material can be used as is, if its pH is equal to or greater than 6.

3.5.1.7. Grading

The performance of granular bases, to a large extent, is dependent upon their gradings, which must conform to stringent standards. The maximum nominal sizes, grading envelopes, as well as coarse sand ratios, for G1, G2, and G3 materials are included in TRH14 and the Standard Specifications, and are summarized in Appendix A of this chapter.

The main aim is to achieve a smooth grading which, after compaction, falls as closely as possible to the mean of the various sieve sizes in the envelope, i.e., runs through the middle of the grading envelope. This ensures that the different sized particles fit snugly into each other, minimising the void content of the material in the compacted base layer, and increasing mechanical interlock between the particles, thus enhancing the material's performance under traffic loads.

Grading Specifications

Grading specifications are based on the individual fractions that make up the grading of the material **after compaction in the road.**

It is usually compulsory to construct a trial section to check that the processing and compaction techniques produce a layer that satisfies the grading and compaction requirements. The additional breakdown of the material during compaction and the variability in grading attributable to production procedures and/or product quality can be assessed from the trial section. Data on the breakdown of the aggregates and resistance to crushing can be used to adjust the grading of the material at the crusher. See Chapter 12: 4.3 for information on trial sections.

The breakdown characteristics of base materials are sensitive to the variability of the source and technique. The implementation of appropriate crushing techniques can produce a consistent product of low variability in all of the required qualities: degree of flakiness, needle-like shape and hardness. Grid rolling, where permitted, flakiness, needle-like shape and insufficient hardness are significant aspects contributing to further breakdown during compaction. The use of vertical shaft impact breakers or gyro discs in the crushing arrangement, on the other hand, tends to reduce breakdown during compaction. See Chapter 8: 3.2 and Chapter 12: 2.1 for information on crusher types.

Alluvial (materials deposited by water) or colluvial (deposited by gravity) deposits, depending on the nature of the matrix, are known to display higher breakdown of the fractions passing the 2.00 mm and 0.425 mm sieves, particularly if impact crushing is not used in the crushing arrangement.

A target grading is derived using the results of tests from the trial section, and acceptance tolerances around which the grading may vary are given in the Standard Specifications. Further limitations are imposed regarding the grading of the 0.075 mm, 0.425 mm and 2.0 mm sieve sizes.

In the case of G1 material, only additional fines, crushed from the same parent rock and of approved quality (not from weathered rock) are allowed. They should normally only be considered when it is shown in the trial section that either:

- The "**coarse sand**" ratio is unsatisfactory.
- The **percentage passing the 0.075 mm sieve** does not comply with the requirements.

For practical reasons, 10 percent is the minimum fines that can be added on the road. However, G1 materials with fines in excess of 24% passing the 0.425 mm screen and 12% passing the 0.075 mm screen (and without smooth gradings) can seldom be compacted to the required density of 88% of apparent density.

For G2 and G3, the same comments as for G1 are applicable, with the exception that natural fines not obtained from the parent rock may be considered for addition. However, the addition of natural sands is not recommended. The lower density requirement means that minor deviations from the specified grading will usually not interfere with achieving the specified density.

Adding Natural Sand

The addition of natural sand to G2 or G3 base is not favoured in view of its detrimental effect on shear characteristics (the particles tend to be rounded in shape), unless proven to the contrary by appropriate laboratory tests and research for the designated source of binder. Crushed fines are much more angular and have a higher surface roughness.

3.5.1.8. Compaction

The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density of the layer with a minimum of voids, while using the least compaction energy. By achieving higher densities, the shear strength and elastic modulus are improved, leading to a lower tendency for additional traffic associated compaction and consequent rutting under traffic, while the deflection of the pavement under wheel loads is also reduced.

Much emphasis is placed on achieving a high degree of compaction in granular base layers. The methods used to achieve this are covered in detail in Chapter 12: 3.8 and Chapter 13: 3.5.2. This includes method specifications for the construction of these layers to ensure that the crushed stone particles are compacted together as tightly as possible.

Minimum compaction requirements vary from one road authority to another. Recommended guidelines are given in Table 9.

Apparent vs Bulk Density

It is preferable to use BD instead of AD-CS as the reference density when the water absorption is greater than 1.0%.

Table 9. Guidelines for Compaction Standards for Crushed Stone Bases

Base Class	Minimum % Apparent Density of Crushed Stone (AD-CS)	Minimum % Bulk Density (BD)	% MDD
G1	86 to 88	–	–
G2	–	85	100 to 102
G3	–	–	98 to 100

3.5.2. Standards for Waterbound Macadam

Waterbound macadam is one of the oldest forms of granular road bases and essentially consists of large, fairly single sized rock fragments, which are placed and levelled across the width of the pavement. After initial rolling to orientate the stone particles, fine aggregate, consisting of either natural sand, crusher sand, or a mixture of the two, is placed on top of this layer. The fine aggregate is introduced between the large stone particles by one or a combination of methods including water jetting, brooming, and static or vibratory rolling. The main aim is to fill the voids between the large stone particles as far as possible, creating a layer with a high level of mechanical interlock.

Waterbound macadam is suited to wet conditions because the coarse granular material interlock is less susceptible to moisture. It is, however, prone to some consolidation under traffic and inexperienced contractors have difficulty in achieving acceptable surface levels.

3.5.2.1. Requirements for the Coarse Aggregate Fraction

The various rock types normally used for granular bases are suitable for use in the coarse aggregate fraction of waterbound macadam; the most commonly used being:

- Dolerite
- Basalt
- Gabbro/Norite
- Granite
- Quartzite
- Dolomite
- Tillite
- Hornfels

Granite and quartzite, especially from mine dump-rock could contain excessive amounts of sulphide minerals, such as iron pyrite, marcasite, and chalcopyrite. These minerals decompose easily in the presence of water and air, forming sulphuric acid and sulphate salts. Problems may be caused by blistering on the surface. Expert opinion should be sought when visible quantities of these minerals are evident in the crushed rock. Similarly, the basic crystalline materials (dolerite, basalt, norite and gabbro) should be checked for durability, using X-ray diffraction, to ensure the absence of excessive smectite clays.

The gradings for waterbound macadam are given in Table 10.

Table 10. Waterbound Macadam Gradings

Coarse Aggregate Grading	
Sieve Size (mm)	**Percent Passing (by mass)**
63	100
50	85 – 100
37.5	0 – 30
28	0 – 5
10	–
Fine Aggregate Grading	
Sieve Size (mm)	**Percent Passing (by mass)**
7.1	100
5	85 – 100
0.075	10 – 20

Other requirements for the coarse aggregate fraction include:

- Maximum **Flakiness Index** of 35
- Minimum dry **10% FACT** 110 kN, minimum wet should be at least 75% of the dry value
- For **tillite**, the minimum dry 10% FACT should be 200 kN, and the wet value 70% of the dry value
- Requirements for soluble salts, based on the electrical conductivity of the material, are the same as for G1, G2, and G3 crushed rock.

3.5.2.2. Requirements for Fine Aggregate Fraction

The fine aggregate used to fill the voids between the large aggregate particles in the waterbound macadam layer can be a crusher dust, made from the same parent material as that crushed for the coarse aggregate fraction, or other finely crushed hard durable rock. It can also consist of fine sand from natural sources, as well as a blend of crusher dust and natural sand.

The grading for the fine fraction is given in Table 10.

Atterberg Limit requirements of the fine aggregate fraction are:

- **Liquid limit** 25 maximum
- **Plasticity index** 6 maximum
- **Linear shrinkage** 3 maximum

3.5.2.3. Compaction of Waterbound Macadam

The construction of waterbound macadam tends to be based on method specifications rather than on end-product specifications. Requirements such as "rolling is continued until no movement of the coarse aggregate is visible and the coarse aggregate is well keyed-in" are used. Nevertheless, minimum compaction requirements are specified, usually between 86% and 90% of apparent density. The measurement of in situ compacted density in such coarse materials is, however, highly problematic.

4. Standards for Bituminous Materials

4.1. Bituminous Binders

This section succinctly deals with standards that apply to bituminous binders, shown in Figure 3. This section should be read in conjunction with Chapter 3: 4 which covers applicable test methods, as well as Chapter 9: 8, which provides insight into the selection of bituminous binders for various applications. Further information is available in TRH21.

Figure 3. Binder

4.1.1. Types and Grades of Bituminous Binders

The chemical composition of a particular bitumen determines its physical properties and performance characteristics. However, the complex and variable chemical and molecular structure of bitumen makes it extremely difficult to define chemical composition to characterise performance. Consequently, it has been general practice worldwide to make use of performance-related physical properties as the primary means of specifying and selecting bituminous binders.

References for Binders

Good references for binders are:

- **The Shell Bitumen Handbook**, 5th Edition (2003)
- TG1: **The Use of Modified Bituminous Binders in Road Construction** (2007)
- TRH21: **Hot Recycled Asphalt** (2009)

Specifications for bituminous binders are intended to ensure that:

- Binders are manufactured to accepted standards that ensure **uniformity** of quality and satisfactory performance.
- They are not adversely affected during normal **handling, transport** and **storage**, even when heated.
- **Changes in binder properties** during correctly controlled applications do not exceed certain limits.

4.1.1.1. Conventional Binders

The specifications for penetration grade bitumen, cutback bitumen and bitumen emulsions published by the South African Bureau of Standards (SABS) as listed in Table 11 are currently applicable in South Africa. For more detail, such as the full range of properties monitored and the limits imposed on them, the relative specification should be consulted. The test methods used to assess compliance with the relevant specifications are dealt with in Chapter 3: 4.1.

4.1.1.2. Modified Binders

Also shown in Table 11 are the various types of modified binders in common use. The requirements that have to be met by modified binders when subjected to testing are set out in TG1 (Tables 1 to 11). The tests incorporated in these requirements are intended to ensure that:

- The **consistency** and **rheological properties** of the binder are appropriate for a range of in-service conditions of traffic and climate.
- The binder can be **safely handled** and is **stable** during storage and handling.
- The **performance characteristics** are not unduly compromised during hot applications, e.g., hot applied binders in seals and binders used in hot mix asphalt.

Homogenous and Non-Homogenous Modified Binders

- **Homogenous Binders:** A blend of polymer and bitumen where two distinct phases cannot be detected. An example is polymer modified binders (EVA, SBR and SBS).
- **Non-Homogenous Binder:** A blend of modifier and bitumen where two distinct phases are detectable. An example is bitumen rubber binders using crumbed rubber.

Table 12 gives the table number in TG1 that sets out the property requirements relevant to the various applications and classes of modified binders.

Table 11. Types and Grades of Bituminous Binders

Type	Grade or Class [1]	Specification
Penetration grade bitumen	35/50 50/70 70/100 150/200	SANS 4001-BT1
Cutback bitumen	MC-30, MC-3 000	SANS 4001-BT2
Modified binders (homogenous) SBS SBR EVA Hydrocarbons	 S-E2, A-E2, S-E1, A-E1, C-E1 A-P1 A-H1, A-H2	TG1
Modified binders (non-homogeneous) Bitumen rubber	S-R1, A-R1, C-R1	
Bitumen emulsion	Cationic Spray grade: 60%, 65% and 70% binder content Cationic Premix grade: 60% and 65% binder content Cationic and Anionic stable mix grade: 60% binder content	Anionic emulsions SANS 4001-BT3 Cationic emulsions SANS 4001-BT4
Modified bitumen emulsion	Inverted cationic emulsion 80% binder content (including flux) SC-E2, AC-E2 SC-E1, AC-E1 CC-E1	SANS 4001-BT5
Precoat Fluids	Proprietry products: bitumen based binders with cutters and adhesion agents.	

Note
1. The codes used for the various grades or classes are explained in detail in TG1.

Table 12. Requirements for Various Applications

Application	Binder Class	Table in TG1
Hot applied polymer modified binders for spray seals	S-E1, S-E2	5
Polymer modified emulsions for spray seals	SC-E1, SC-E2	6
Polymer modified binders for hot mix asphalt	A-E1, A-E2, AP-1	7
Bitumen rubber for spray seals and asphalt	S-R1, A-R1	8
Hydrocarbon modified binders for hot mix asphalt	A-H1, A-H2	9
Modified binder crack sealants	C-E1, CC-E1,C-R1	10
Polymer modified emulsions for machine-applied microsurfacing	AC-E1 (overlays) AC-E2 (rut filling)	11

Requirements for stone precoating fluids are covered in Section 4.5.2.

4.2. Hot Mix Asphalt

This section includes the various standards for hot mix asphalt surfacing and asphalt bases. In some areas, there is a fine line between "standards", "test protocols" and "materials utilisation and design", and frequent reference is made between this section of Chapter 4 and Chapter 3: 4.2 and Chapter 9: 10.

Standards for hot mix asphalt encompass the various components from which it is manufactured, including:

- Aggregates
- Filler
- Bituminous binders

As covered in Chapter 8: 4.3 and Chapter 9: 10.1, increasing attention is being paid to recycling asphalt that is reclaimed from existing pavements, and applicable standards for reclaimed asphalt (RA) should be taken into account.

4.2.1. Engineering Properties

To ensure that the hot mix asphalt performs satisfactorily over its design life, standards have been developed to ensure that the asphalt meets certain engineering properties. These are covered in more detail in Chapter 9: 10, but can be summarised as:

- Durability
- Resistance to cracking
- Resistance to permanent deformation
- Resistance to shrinkage
- Flexibility
- Skid resistance for wearing course layers
- Permeability
- Stiffness (elastic modulus)
- Workability

4.2.2. Mix Categories

Asphalt mixes are categorised into two broad "packing' types: stone skeleton and sand skeleton mixes, which are illustrated in Figure 4.

- In **stone skeleton** mixes the spaces between the coarser aggregate fractions is filled by the finer aggregate fractions to a degree that the coarser aggregates are not pushed apart. Contact between the coarser fractions is thus assured. This situation results in the loads on the layer being carried predominantly by a matrix (or skeleton) of the coarser fraction.
- In **sand skeleton** mixes, the loads on the layer are carried mainly by the finer fraction, with the larger fractions providing bulk and replacing a proportion of the finer fraction. There is no meaningful contact between the individual larger aggregate particles.

Designing HMA

For details of the composition, selection and design of asphalt surfacings, refer to:

- **Interim Guidelines for the Design of Hot Mix Asphalt in South Africa** (September 2001)
- **User Guide for the Design of Hot Mix Asphalt** (Sabita Manual 24, June 2009)
- TRH8. **Design and Use of Hot-Mix Asphalt in Pavements**.
- Chapter 9, **Materials Utilisation,** Section 10.8

SABITA is compiling a new "**Asphalt Mix Design Manual for South Africa**". This new guideline will supersede the references listed here. Most of the basics and principles will essentially remain the same, but the details of the design method will be updated. The new manual will be released by SABITA through the Society for Asphalt Technology (SAT) in late 2014 and 2015. Contact SABITA, www.sabita.co.za.

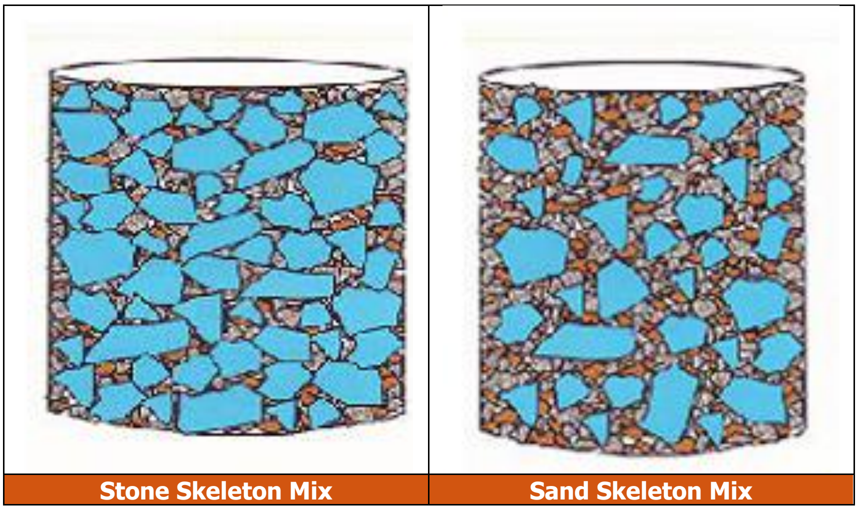


Figure 4. Illustration of Stone and Sand Skeleton Mixes

4.2.2.1. Selection of Appropriate Mix Designs

The selection of the most appropriate asphalt mix design is covered in detail in Chapter 9: 10 and only a brief summary is included in this section.

Asphalt mixes are divided primarily into function and structural applications. The functional layers, which serve as surfacing layers, are designed to provide properties such as a high skid resistance, noise reduction, good riding quality, and resistance to water penetration. Functional layers may be divided further into "thin asphalt" (layer thickness > 30 mm) and "Ultra Thin Friction Course" (< 30 mm). Structural layers are those with layer thickness of greater than 40 mm, and may consist of either surfacing or base mixes.
Typical gradings of various mix types are listed below and illustrated in Figure 5.

- **Gap-graded mixes, sand skeleton type (AG):** These mixes are seldom used due to scarcity of suitable sand, high binder contents resulting in relatively high cost, and likely lower resistance to rutting, particularly in hot climatic areas.
- **Continuously graded mixes (AC):** Continuously graded mixes are routinely used for both surfacing and base mixes. They consist mostly of graded crushed stone but may contain a small proportion of natural sand.
- **Open-graded mixes (AO):** This mix type is mostly used in surfacing layers and is usually manufactured using bitumen rubber, producing mixes with good durability.
- **Stone Mastic Asphalt (SMA):** This stone skeleton type mix is used as a surfacing layer. The skid resistance of SMA tends to be superior to that of continuously graded surfacing mixes.

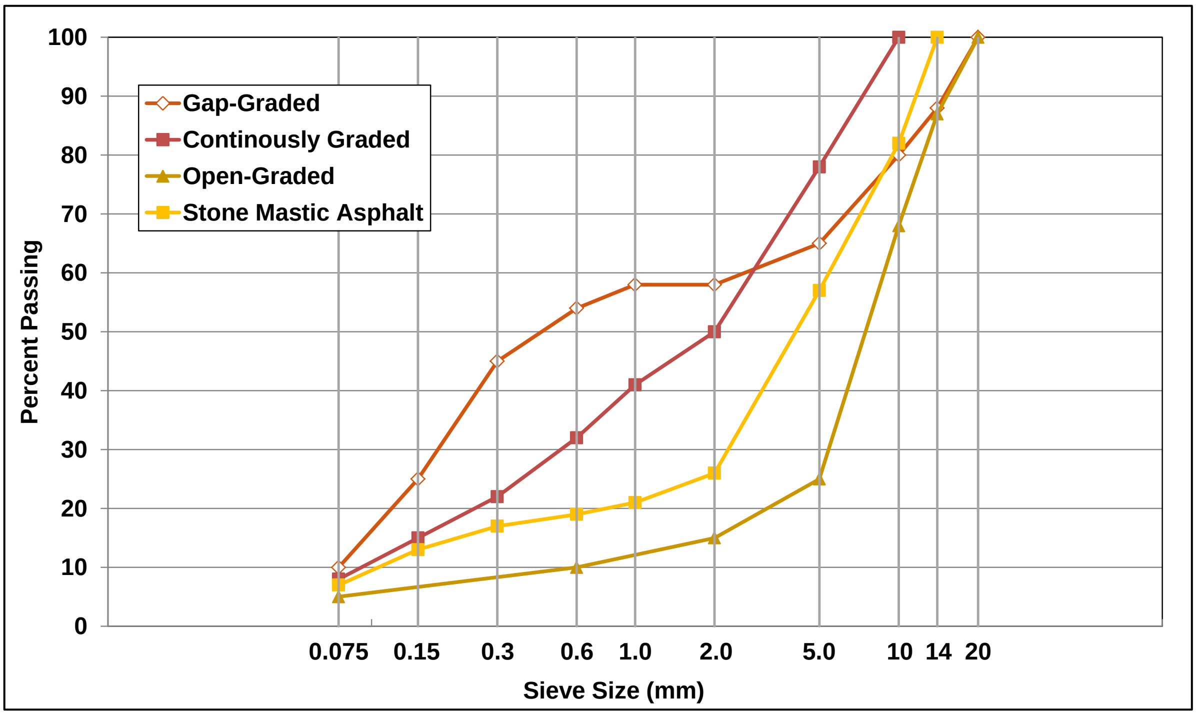


Figure 5. Aggregate Grading Types

4.2.3. Asphalt Surfacing

Asphalt surfacings can be divided into two broad categories in terms of the primary purpose served by such layers:

- **Structural layers** generally have a thickness of more than 40 mm. These layers contribute to the strength of the pavement and provide adequate skid resistance for the traffic and climate conditions.
- **Functional layers** commonly are less than 30 mm. These layers do not contribute significantly to pavement strength and can best be described as surface dressings that meet functional criteria such as:
  - A suitable **surface texture** for skid resistance, noise reduction and surface water drainage given the traffic volumes, speed and prevailing climate.
  - **Sealing** of the substratum against water penetration.
  - Limited improvement of **riding quality**.

  Functional layers are used in two distinct applications:
  - Firstly, **thin asphalt layers** for low speed and light traffic applications, in residential areas.
  - Secondly, ultra-thin friction courses (**UTFC**) for high volume, often high speed, applications on major highways

> **Asphalt Surfacing**
>
> *Layers ≥ 40 mm* are **structural** layers and contribute to the pavement's structural strength. *Layers < 30 mm* are commonly **functional layers** that primarily act as surface dressings.

Asphalt surfacings provide the interface between the tyres of traffic and the main structural layers of the pavement. Besides meeting the engineering properties covered in Section 4.2.1, they should provide sufficient surface texture for adequate skid resistance.

The aggregate packing in asphalt surfacings can be either sand or stone skeleton types, depending on the primary function of the layer.

To achieve the desired properties, the use of a modified binder in the mix should be considered, the most generally used bitumen modifiers being:

- Rubber crumb
- Styrene-butadiene-rubber (SBR) latex
- Styrene-butadiene-styrene (SBS)
- Ethylene-vinyl-acetate (EVA)
- Aliphatic synthetic wax
- Naturally occurring hydrocarbons

Guidelines on the use of modified binders in asphalt surfacing mixes, covering the composition of homogenous and non-homogenous binders, their relative benefits, as well as their cost-effectiveness, are covered in TG1.

In cases where reclaimed asphalt (RA) is added to the asphalt surfacing mixes, TRH21 makes recommendations on the maximum proportions of RA, ranging from 3% when used in SMA type mixes, to 18% when used in conventional surfacing mixes.

4.2.3.1. Maximum Aggregate Size

The nominal maximum aggregate size in the mix should be selected with due consideration of the intended layer thickness. Except for UTFC's, it is generally accepted that the maximum aggregate size should be at most one third of the layer thickness to ensure compactibility and to counter segregation during paving, which increases the permeability of the layer. More detailed recommendations are given in Chapter 9: 10.5.1.3.

Maximum Aggregate Size

For continuously graded mixes, the maximum aggregate size should not exceed 1/3 of the layer thickness. This is primarily to prevent segregation during construction, which could increase permeability, and to enable the required level of compaction to be achieved.

The same requirement is not necessary for UTFC where the aggregates are essentially single size and segregation is not an issue.

4.2.3.2. Gradings of Aggregate Blends

A range of aggregate gradings have been used with success in South Africa. However, the choice of aggregate gradings used in asphalt surfacing mixes has changed over the years, due to factors such as the scarcity of good quality natural sand, the growth in traffic loadings which necessitates mixes with high rut resistance, and worldwide advances in asphalt mix design technology.

Apart from maximum aggregate size, three distinct fractions are defined to describe a particular grading. These are:

- **Coarse aggregate**: particles retained on the 5 mm sieve
- **Fine aggregate**: particles passing the 5 mm sieve
- **Mineral filler**: particles passing the 0.075 mm sieve

Specific gradings in general use are shown in Table 13 to Table 16. These should be regarded as guidelines for the designer who should determine the target project grading on the basis of:

- Consistently **available** aggregates.
- The bituminous **binder** that is considered appropriate for the application.
- Appropriate **aggregate packing** that, with the binder, will ensure that the required engineering properties are met.

Table 13. Gradings for Asphalt Surfacing with Conventional Binders

Sieve Size (mm)	Continuously Graded		
	Coarse	Medium	Fine
28	100		
20	88 – 100		
14	73 – 86	100	
10	64 – 77	85 – 100	100
5	44 – 62	56 – 77	66 – 89
2	27 – 45	33 – 48	42 – 59
1	21 – 35	25 – 40	31 – 51
0.6	16 – 28	18 – 32	24 – 40
0.3	12 – 20	11 – 23	16 – 28
0.15	8 – 15	7 – 16	10 – 20
0.075	4 – 10	4 – 10	4 – 12

Table 14. Gradings for Continuously Graded Asphalt Surfacing with Non-Homogeneous Modified Binders

Sieve Size (mm)	Maximum Stone Size	
	14 mm	20 mm
20		100
14	100	86 – 97
10	83 – 100	72 – 86
5	53 – 72	47 – 64
2	30 – 47	26 – 43
1		17 – 30
0.600	13 – 25	13 – 25
0.300	8 – 18	10 – 18
0.150		6 – 13
0.075	4 – 8	4 – 10
Nominal Mix Proportions		
Aggregate	91%	
Modified binder	7%	
Active filler	2%	

Table 15. Gradings for Stone Mastic Asphalt (SMA) Surfacing with Modified Binders

Sieve Size (mm)	Maximum Stone Size		
	14 mm	10 mm	7 mm
14	100		
10	72 – 91	100	
7.1	45 – 69	57 – 83	100
5	31 – 52	33 – 59	82 – 100
2	20 – 31	21 – 31	31 – 41
1	16 – 26	16 – 26	22 – 32
0.600	14 – 24	14 – 23	18 – 30
0.300	11 – 23	11 – 22	13 – 25
0.150	9 – 17	9 – 19	9 – 19
0.075	7 – 12	7 – 12	7 – 12

Table 16. Gradings for Open-Graded Asphalt Mixes with Non-homogenous Modified Binders

Sieve Size (mm)	Open Graded Asphalt Mixes
20	100
14	91 – 100
10	38 – 58
5	11 – 22
2	8 – 14
0.600	–
0.300	–
0.075	2 – 6
	Nominal Mix Proportions
Binder Type	**Bitumen Rubber**
Aggregate	93.5%
Binder Content	5.5%
Active Filler	1.0%

The grading of crumb rubber in bitumen rubber mixes should conform to that shown in Table 17.

Table 17. Gradings for Crumb Rubber in Bitumen Rubber Mixes

Sieve Size (mm)	Crumb Rubber
1	100
0.600	40 – 70
0.075	0 – 5

4.2.3.3. Constituent Materials: Aggregates

Aggregates, used in asphalt surfacing mixes, such as those in Figure 6, should meet the following general requirements:

- Coarse and fine aggregate obtained from crushing or natural sources should be **clean** and free from decomposed materials, vegetable matter and other deleterious substances.
- The aggregate blend may contain **natural fines** not obtained from the parent rock being crushed, subject to limitations of the proportion of such materials based on mix type and experience with the materials.
- The **coarse aggregate**, i.e., the material retained on the 5 mm sieve, is, in most cases, crushed rock. Certain types of crushed blast-furnace slag may also be used, provided they satisfy the strength requirements and are not too water absorbent.
- The **fine aggregate**, i.e., the material passing the 5 mm sieve and retained on the 0.075 mm sieve, may be crusher sand, clean natural sand, mine sand, selected river gravel or a mixture of these.

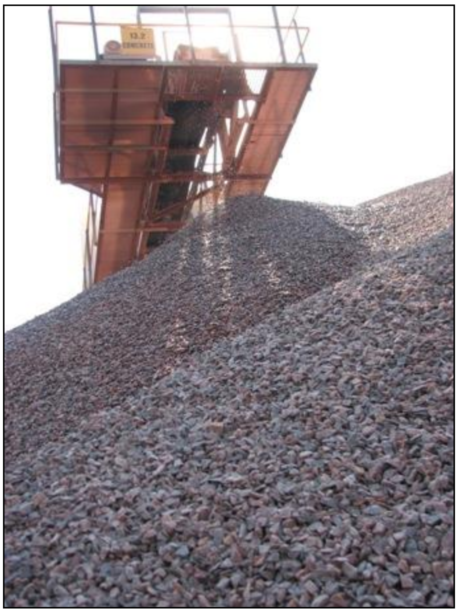


Figure 6. Aggregate

To improve the skid resistance, especially of gap-graded and semi-gap graded mixes, rolled in chips are rolled into the paved mat prior to compaction. These are stone chips that have been precoated with a penetration grade

Problematic Materials

- The use of **dolomite, felsite and norite** as aggregate for asphalt surfacings require special investigations and should only be used with the express approval of the client as they may affect the performance of the asphalt mix.
- **Argillaceous** rocks are generally considered to be unsuitable.
- **Pedogenic materials (ferricrete, silcrete and calcrete)** have been found not to perform satisfactorily in wearing courses, even if these materials meet all the requirements of the standard tests. In cases where it is necessary to use these materials, it is recommended that a detailed investigation be carried out to ensure satisfactory performance.

bitumen, as specified in the Standard Specifications. These finished surfacing is illustrated in Figure 7. Single sized aggregates of maximum size 14 mm are used for this purpose. Aggregates of maximum size 20 mm are suitable only for layers of thickness of 40 mm or greater or semi-gap graded mixes.

i. Grading

For consistent asphalt, aggregates for asphalt surfacings comprise blends of single sized aggregates. Normally 14 mm, 10 mm and 7.1 mm nominal sizes are used for the range of layer thickness common in South Africa. The single sized aggregates actually consist of several aggregate sizes, with specific gradings. They are blended in a mixing plant with finer aggregates in the correct proportions for the approved project mix. The grading requirements for the above nominal aggregate sizes are given in Table 18.

Rolled in Chips

The use of rolled in chips in continuously graded asphalt should be approached with extreme caution, taking into account factors such as:

- **Layer thickness**. Not recommended when the layer thickness is 40 mm or less
- **Grading**. Finer gradings are required on thin layers to accommodate the chips.
- **Permeability**. The adverse effect on the permeability of the layer should be checked on a trial basis prior to acceptance.

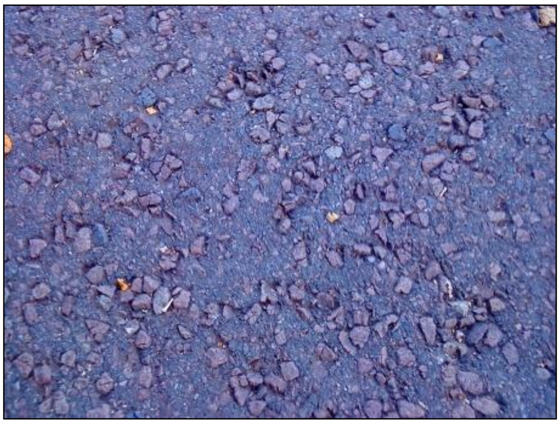


Figure 7. Example of Rolled in Chips

Table 18. Gradings of Single Sized Aggregate

Sieve Size (mm)	Grade	Percentage by Passing (Mass)				
		Nominal size (mm)				
		14	10	7.1	5	2
37.5	1 & 2					
28						
20		100				
14		90 – 100	100			
10		13 – 41(1)	90 – 100	100		
7.1		0 – 7(2)	13 – 41(1)	90 – 100	100	
5			0 – 7(2)	13 – 41(1)	90 – 100	100
3.35					0 – 30	
2.0				0 – 4(3)	0 – 4	0 – 100
	3	Gradings shall comply with the requirements for Grades 1 and 2 with the following exceptions: (1) 0 – 58 (2) 0 – 15 (3) 0 – 8				
Fines content material passing a 0.425 mm sieve % (m/m) maximum	1	0.5			1.0	15
	2	1.5			2.5	15
	3	2.0		3.0	3.5	15
Dust content material passing a 0.075 mm sieve % (m/m) maximum	1	N/A				2.0
	2	0.5		1.0		2.0
	3	1.5				2.0

Aggregate for rolled-in chips should meet the grading criteria shown in Table 19.

Table 19. Gradings for Rolled in Chips

Sieve size (mm)	Percentage by Mass Passing	
	20 mm chips	14 mm chips
20	100	
14	0 – 20	100
10	0 – 5	0 – 20
7.1	0 – 1	0 – 5
0.425	0.5 max	0.5 max

ii. Physical Properties of Aggregates

- **Hardness/Toughness.** The coarse aggregates in the asphalt mix are subjected to abrasion during the various stages of production, manufacture and placement of the asphalt layer after which the process continues under traffic. The test methods used to evaluate hardness and toughness and their requirements are listed in Table 20.

  In cases where there is uncertainty about the durability of the aggregate, it is prudent to perform the 10% FACT test on wet material after soaking for 24 hours, followed by draining. In such cases, the wet value should be at least 75% of the dry value.
  The values given in Table 20 apply to most groups of natural materials. Nevertheless, it is recommended that the 10% FACT is somewhat higher for tillite (diamictite) (170 kN) and calcrete (180 kN).

- **Durability and Soundness**. These measures assess the ability of aggregates to resist breakdown and disintegration under the action of the environment, e.g., wetting, drying and freeze/thaw cycles. The ethylene glycol soundness test is used to evaluate the durability of suspect aggregates. In this test, potentially deleterious clay minerals within the aggregate particles swell, thus breaking down the aggregate.

  Excessive absorption of water has an adverse effect on the durability of asphalt mixtures and could also be indicative of aggregates that will absorb undue quantities of bituminous binder. Hence, the water absorbed in both the coarse and fine aggregates should be limited, as detailed in Table 20.

  If it is unavoidable to use aggregate with water absorption in excess of the stated limits, it is recommended that a detailed investigation be carried out to ensure the satisfactory performance of the asphalt.

Beware of Problems in Finer Aggregate

Note that these tests are applied to the coarse aggregate fraction only, i.e., material retained on the 5 mm sieve size. Hence designers and manufacturers should be aware of weaker zones in the source quarry which may only manifest in the finer aggregate fractions.

- **Particle Shape and Surface Texture**. Both the stability and workability of asphalt is affected by the shape of the aggregate particles. For heavy traffic applications, particles should be angular to ensure good stability. For lighter traffic applications, more rounded aggregate may be tolerated to promote workability, especially in the case of thin layers encountered on residential streets.

  As a general guideline, when aggregates are produced from sources other than solid rock, it is recommended that 95% of the particles should have at least three fractured faces.

  Extreme angularity, e.g., flat, thin and elongated particles should always be avoided as these shapes will cause difficulties during paving and compaction of the asphalt layer.

  Rolled-chips should be of a sufficiently cubic shape to enable adequate embedment to prevent chip loss under traffic.

  Aggregates with a rough, sandpaper-like surface are conducive to mixes where resistance to permanent deformation (rutting) is important, i.e., for heavy traffic applications accompanied by high ambient temperatures. Smooth textured aggregates may be considered for low traffic applications where workability is generally more important than stability.

The surface texture of aggregates used in asphalt surfacings also influences the skid resistance of the layer. Harsh sandpaper-like textures promote micro-texture, which provides skid resistance at low-speeds.

The aggregate polishing value test is a measure of the durability of surface texture as a result of polishing by vehicle tyres. The flakiness index and fractured faces are a measure of the shape of particles. The limits associated with these tests are detailed in Table 20.

- **Cleanliness**. Cleanliness of aggregates refers to the absence of foreign and deleterious materials, such as vegetation, shale, soft particles, clay lumps or coatings and excess dust. In exceptional cases, cleanliness can be ensured by washing of the aggregates. Tests that can be used to quantify aggregate cleanliness are listed in Table 20.

iii. Chemical Properties of Aggregates

The most significant chemical property of an aggregate is how well it adheres to a bituminous binder. The bond that forms when bitumen coats the surface of aggregate can weaken in the presence of water. Where aggregates have a greater affinity for water than for bitumen, so-called hydrophilic or water-loving aggregates, the binder film on the aggregate may become detached or "strip" in the presence of water.

Several tests have been proposed to evaluate the susceptibility to stripping of aggregate. However, none of these can consistently identify mixes with high stripping potential. Notwithstanding, the Modified Lottman test (ASTM D4867) is generally regarded as the best test for evaluation of the stripping potential of an aggregate. The Hamburg Wheel Tracking Test should also be considered as a means of studying stripping potential. See Chapter 3: 4.2.5.

Special precautions may be required for crushed blast furnace slag aggregates to ensure that they are properly hydrated before use. To ensure that all expansion of the aggregate has taken place, the coarse fractions should be kept wet for at least three months after crushing. It is not necessary to hydrate the fine fractions after crushing as they become fully coated with the binder and are therefore not affected by moisture, which could cause expansion. See Chapter 8: 4.5 for more on slags.

Table 20. Physical Properties of Aggregates

Property	Test	Acceptance Criteria and Comments
Hardness / Toughness	**Fines Aggregate Crushing Test** (10% FACT) Dry	Done on -14 +10 mm fraction Minimum: 160 kN: Dense graded surfacings excluding open-graded SMA mixes 210 kN: Open and semi-open-surfacings and SMA
	Wet	Minimum: 75% of dry value
	Aggregate Crushing Value (ACV)	Dense graded surfacings excluding open-graded and SMA mixes: minimum 25% Open- and semi-open-graded and SMA mixes: minimum 21% Rolled-in chips: minimum 18%
Durability / Soundness	**Ethylene Glycol**	Visual evaluation
	Water absorption by mass	Coarse Aggregate: maximum 1% Fine aggregate: maximum 1.5%
Particle shape and texture	**Flakiness Index**	20 and 14 mm aggregate: maximum 25 10 and 7.1 mm aggregate: maximum 30 Rolled-in chips: maximum 20
	Polished Stone Value (PSV)[1]	Minimum 50
	Fractured faces	At least 95% of all particles should have three fractured faces.
Cleanliness	**Sand equivalent test**	Total fines fraction: minimum of 50 Natural sand fraction to be mixed with aggregate (where permitted): minimum 30
	Clay lumps and friable particles	Visual inspection

Note:
1. The values for PSV relate to general conditions. Where traffic is heavy, and where skidding may be a hazard, such as at approaches to intersections, roundabouts, steep grades and tight curves with insufficient super elevation, it is appropriate to adopt a minimum value of 55. Similarly, for lower traffic volumes and lower operating speeds, a PSV of 47 is probably satisfactory.

iv. Filler

The physical and chemical properties of fillers are covered in Chapter 9: 10.5.2.2. Fillers should meet the following criteria:

- **Percentage** mass passing the 0.075 mm sieve: minimum 70
- **Bulk density** in toluene: 0.5 – 0.9 g/mℓ
- **Voids** in the compacted filler: 0.3 – 0.5%

v. Chemical Properties of Fillers

Fillers from natural sources that have excess clay minerals or adsorption potential may have adverse effects on the mix in terms of premature hardening and stripping. It is recommended that the Methylene Blue test, as described in Appendix A of the Interim Guidelines (Asphalt Academy, 2001) and Chapter 3: 4.2.3, is used as a means of assessing the amount and activeness of clay minerals in the filler. Experience has shown that methylene blue values of 5 or less are indicative of high quality filler. Fillers with methylene blue values above 5 should be further investigated by means of hydrometer analysis and the determination of Atterberg limits.

4.2.3.4. Constituent Materials: Reclaimed Asphalt

The use of reclaimed asphalt (RA) is covered in TRH21, with the most pertinent aspects being summarised in Chapter 8: 4.3 and Chapter 9: 10.5.2.3. In South Africa, RA is generally obtained from milling, but also from the excavation of existing asphalt pavements or stockpiles of discarded or surplus asphalt. It is then crushed and screened to achieve a reasonably well graded, free flowing, and consistent product. As with virgin aggregates, RA should be free of foreign, deleterious material such as unbound granular base, broken concrete and crumbed rubber. A RA stockpile is illustrated in Figure 8.

Figure 8. Reclaimed Asphalt (RA) Stockpile

4.2.3.5. Constituent Materials: Bituminous Binders

The bituminous binder should be selected with due consideration of the aggregate packing (grading) of the mix, in conjunction with traffic and environmental conditions. More details on binder selection are covered in Chapter 9: 8.1.

4.2.4. Asphalt Base

Asphalt bases are designed to distribute the traffic loads. They should be resistant to deformation and should remain durable over their design lives. Reclaimed asphalt (RA) may be incorporated in asphalt base mixes. TRH21 recommends a maximum RA content 27% for asphalt bases.

4.2.4.1. Mix Types

Larger maximum aggregate sizes are selected for asphalt bases. Gradings are generally either coarse continuous or SMA type, with significantly larger maximum aggregate sizes.

The choice of appropriate grading and mix types for asphalt bases is discussed in more detail in Chapter 9: 10.6. The designer must consider the workability and compactibility of the mix to ensure uniformity and adequate compaction of the finished layer.

4.2.4.2. Maximum Aggregate Size

The nominal maximum aggregate size in the mix should be selected with due consideration of the intended layer thickness. As with surfacings, it is generally accepted that the maximum aggregate size should be at most one third of the layer thickness. This is to ensure compactibility and to counter segregation during paving. More detailed recommendations are given in Chapter 9: 10.5.1.3.

4.2.4.3. Grading of Aggregate Blends

Apart from the maximum aggregate size, three distinct fractions are defined to describe a particular grading:

- **Coarse aggregate**: particles retained on the 5 mm sieve
- **Fine aggregate**: particles passing the 5 mm sieve
- **Mineral filler**: particles passing the 0.075 mm sieve

Specific gradings in general use, i.e., continuous and semi-gap gradings, are shown in Table 21. Other gradings that ensure proper packing of the aggregate and for extreme traffic conditions can also be used. The gradings shown should be regarded as guidelines for determining the target project grading on the basis of:

- Consistently **available** aggregates
- An appropriate **bituminous binder**
- Appropriate **aggregate packing** that, with the binder, ensures that the required engineering properties are met.

Table 21. Gradings for Asphalt Bases

Sieve Size (mm)	Maximum Nominal Size (mm)			
	Semi-gap		Continuously Graded	
	37.5	28	37.5	28
	Percentage Passing Sieve by Mass			
37.5	100		100	
28	87 – 100	100	86 – 95	100
20	77 – 96	93 – 100	73 – 86	87 – 96
14		83 – 94	61 – 76	73 – 85
10	61 – 81	73 – 88	52 – 68	64 – 79
7.1		62 – 77		
5	46 – 61	51 – 65	37 – 54	43 – 61
2	39 – 51	39 – 51	23 – 40	28 – 44
1	35 – 46	35 – 46	17 – 32	20 – 35
0.600	32 – 42	32 – 42		15 – 30
0.300	22 – 35	22 – 35	9 – 21	11 – 24
0.150	10 – 20	10 – 20	6 – 17	8 – 19
0.075	4 – 10	4 – 10	4 – 10	4 – 10

4.2.4.4. Constituent Materials: Aggregates Used in Asphalt Bases

Aggregates used in asphalt base mixes should meet the following general requirements:

- Coarse and fine aggregate obtained from crushing or natural sources should be **clean and free** from decomposed materials, vegetable matter and other deleterious substances.
- The aggregate blend may contain **natural fines** not obtained from the parent rock being crushed, subject to limitations of the proportion of such materials, based on mix type and experience with the use of such materials.
- Aggregates of **argillaceous origin** (e.g., shale, mudrocks) should not be used.
- **Pedocretes** (e.g., ferricrete, calcrete, silcrete and dorbank) may be considered, subject to an investigation into their suitability.

- **Coarse aggregate**, i.e., the material retained on the 5 mm sieve, is, in most cases, crushed rock. Certain types of crushed blast furnace slag may also be used, provided they satisfy the strength requirements and are not too water absorbent.
- **Fine aggregate**, i.e., the material passing the 5 mm sieve and retained on the 0.075 mm sieve, may be crusher sand, clean natural sand, mine sand, selected river gravel, or a mixture of these.

i. Grading

In the interests of consistent asphalt quality, aggregates for asphalt bases comprise blends of single sized aggregates. Normally 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm and 7.1 mm nominal sizes are used for the range of layer thickness commonly adopted in SA. These single-sized aggregates are then blended in a mixing plant with finer aggregates in the correct proportions to achieve the requirements of the approved project mix. Grading requirements for the 37.5 mm to 20 mm nominal aggregate sizes are given in Table 22. Finer aggregate should comply with the requirements of Table 20.

Table 22. Gradings for Single Sized Aggregates

Sieve Size (mm)	Percentage by Mass Passing		
	Nominal Size (mm)		
	37.5	28	20
Grades 1, 2 & 3			
37.5	85 – 100	100	
28	13 – 41	90 – 100	100
20	0 – 7	13 – 41	90 – 100
14		0 – 7	13 – 41
10			0 – 7

	Fines content[1]: maximum	Dust content[2]: maximum
Grade 1	0.5	N/A
Grade 2	1.5	0.5
Grade 3	N/A	N/A

Notes
1. Fines content: material passing a 0.425 mm sieve % (m/m)
2. Dust content: material passing a 0.075 mm sieve % (m/m)

ii. Physical Properties of Aggregates

The same principles listed in Section 4.2.3.3.ii for asphalt surfacing mixes apply to asphalt bases. Specific requirements are listed in Table 23.

Table 23. Physical Properties of Aggregates for Aggregate Bases

Property	Test	Acceptance Criteria and Comments
Hardness/ Toughness	**Fines Aggregate Crushing Test** (10% FACT) (Done on: 10 to 14 mm fraction)	Minimum: Dry: 160 kN 210 kN for rolled in chips Wet: 75% of dry value after soaking
	Aggregate Crushing Value (ACV)	Minimum: 25%
Particle shape and texture	**Flakiness Index** Weighted average of these fractions: 20 to 28 mm 14 to 20 mm	Maximum: 35
	Fractured faces	At least 50% of all particles retained on a 5 mm sieve should have at least one fractured face
Durability/ Soundness	**Ethylene Glycol**	Visual evaluation
	Water absorption by mass	Maximum: Coarse Aggregate 1% Fine aggregate 1.5%
	Plasticity Index	Maximum: 6

iii. Filler

The general requirements listed in Chapter 9: 10.5.2.2 apply here as well. Fillers consist of fine powders; a large proportion of their particles pass through the 0.075 mm sieve. They can be divided into two categories:

- **Active fillers:** hydrated lime and portland cement
- **Inactive fillers:** bag house fines and fly ash

A basic function of fillers is to assist in filling the voids in the mix. Another purpose is to act as a binder extender, stiffening the mastic portion of the mix, and hence the mix itself. When the aggregates used in the mix have poor bitumen adhesion properties, an active filler, usually hydrated lime, can be used as an anti-stripping agent.

iv. Reclaimed Asphalt

The general requirements, and those pertaining to fractionating and control of moisture as outlined in Section 3.3 and covered in detail in TRH21, also apply to asphalt bases.

4.2.4.5. Bituminous Binders

The selection of the most appropriate bituminous binder is covered in Chapter 9: 10.6.2.4.

Cores Less Than 30 mm Thick

It is difficult to determine the in situ density of cores of thickness less than 30 mm. It is suggested that permeability, in conjunction with the observation of adequate compaction procedures, be used as the primary criterion for such layers.

4.2.5. Compaction

Achieving adequate compaction is critically important to ensure satisfactory performance of an asphalt layer. It is good practice to specify both a minimum and maximum compaction requirement for asphalt of thicknesses 30 mm and more. While the need for a minimum requirement is self-evident, a maximum density requirement is adopted to prevent over-compaction which could lead to:

- **Bleeding**
- **Permanent deformation** in the form of rutting, shoving and corrugations

The criteria shown in Table 24 are generally adopted, but should be examined for relevance in specific, severe cases.

Table 24. Compaction Criteria

Maximum Aggregate Size (mm)	Application	Typical Thickness (mm)	Minimum Field Density[1] (% of MVD[2])	Optimal Field Density[1] (% of MVD)
10	Surfacing	30	92.5	93
14	Surfacing	40	93	94
20	Surfacing	50	93	94
28	Base	75	93	96
37.5	Base	100	94	96

Note:
1. All individual values should exceed the minimum.
2. MVD = maximum voidless density. Historically termed the Maximum Theoretical Relative Density (MTRD), or "Rice" density.

4.2.6. Performance Grade Specifications

At the time of this 2014 revision, the process of translating from the current empirical type specification for bituminous binders, contained in SANS 4001-BT1 and TG1, to a performance grade (PG) system has commenced. The key purpose of the PG framework is to ensure that bituminous binders have characteristics that ensure adequate resistance to three types of damage, termed damage resistance characteristics (DRC):

- Viscous deformation
- Fatigue
- Low temperature fracture

Additionally, the viscous behaviour at elevated temperature (135 ºC) will be specified to ensure adequate handling and coating qualities at elevated temperatures.

It is the intention of PG specifications to ensure that the testing carried out on bituminous binders form the basis of a specification that is "blind" to polymer modification. This is to ensure that binders compete on a fair basis, in the interests of objective decisions and cost-effectiveness.

The proposed specification framework will provide for:

- Two **climatic zones** in terms of elevated temperature.
- **Categories of traffic**, ranging from light to extra heavy loading.
- **Compliance criteria** for fresh binders, as well as both short and long-term aged binders, based on the identified damage resistance characteristics. Depending on the characteristic being assessed, tests will be performed on fresh binder, short-term aged in a Rolling Thin Film Oven and medium term aged in the Pressure Ageing Vessel.

Compliance criteria will be based largely on the rheological properties of binders. It is currently the goal to carry out all rheological testing in a dynamic shear rheometer (DSR) in the interests of limiting the number of specialist laboratory equipment items required. A number of DSR's have already been acquired by laboratories in South Africa and a programme of preliminary comparative testing has commenced.

In considering the development of appropriate criteria to safeguard a suitable binder performance quality, it should be borne in mind that the characteristics of the binder alone do not safeguard adequate performance of an asphalt layer or a spray seal. The configuration of aggregate particles and filler has a significant effect. What is achievable is ensuring that the binder, the glue that holds aggregate particles together, is of such a quality to augment the role and function of the other components of the layer to ensure adequate performance.

Research and investigations are underway in South Africa to develop criteria to ensure that binders operating in a range of climatic and traffic conditions contribute to the prevention of damage.

A performance grade specification has been developed in the USA, which influences the formulation of performance grade specifications in South Africa. It is however based on performance criteria for asphalt layers. It is most likely impractical to have distinct sets of specifications for binders used in asphalt and spray seals. Therefore, precautions need to be taken to ensure that specific requirements for the performance of binders in spray seals need to be considered.

4.3. Cold Mix Asphalt

Cold mix asphalt essentially consists of an asphalt mix intended to be laid cold. It can be manufactured in a hot mix asphalt plant, or, can be cold-mixed on site.

4.3.1. Aggregate Grading

Typical gradings for cold mix asphalt are given in Table 25.

Table 25. Typical Grading for Cold Mix Asphalt

Sieve Size (mm)	Percentage Passing by Mass
14	100
10	85 – 100
5	56 – 75
2	28 – 45
1	–
0.600	13 – 25
0.300	8 – 18
0.150	–
0.075	4 – 8
Nominal Mix Proportions by Mass:	
Aggregate	93%
Binder (residual bitumen)	6%
Active filler	1%

4.3.1.1. Binders Used in Cold Mix Asphalt

Different types of binders are used in cold mix asphalt:

- **Cutback bitumen**
- **Bitumen emulsion**: anionic or cationic premix grade
- **Proprietary products**

The SANS specifications for emulsions are SANS 4001 BT3 for anionic emulsions, BT4 for cationic emulsions and BT5 for inverted emulsions. Relevant specifications for these products are given in Table 26. Proprietary products should be Agrément certified as fit for the specific purpose.

Proprietary Products in Cold Mix

Cold mix asphalt is often produced using propriety mixes where the shelf life, as well as the hardening rate, is considerably varied.

Table 26. Specifications for Premix Grade Bitumen Emulsion

Property	Premix Grade Bitumen Emulsion			
	Anionic		Cationic	
	Minimum	Maximum	Minimum	Maximum
Viscosity at 50°C (Saybolt Furol)	25	50	51	200
Binder content % (m/m)	60	62	65	68
Residue on sieving (g/100ml)	0	0.25	0	0.25
Sedimentation after 60 complete revolutions	Nil	Nil	Nil	Nil
Coagulation value % (m/m), dolerite chippings	0	25	N/A	N/A
Fluxing agent content of binder % (m/m)	N/A	N/A	5	10
Particle charnge: Modified procedure	N/A	N/A	positive	positive

As a rough guide, bagged cold mixes can be expected to have a shelf life of 3 to 6 months, while it should be used within 1 to 4 weeks when left in an open stockpile.

To reduce the risk of trapping volatiles in the cold mix asphalt layer after laying, which is likely to cause premature rutting and deformation, it should be left unsurfaced as shown in Table 27.

Cold Mix Layer Thickness

The maximum recommended thickness of cold mix layers is 30 mm.

Table 27. Guidelines for Delay Before Surfacing Over Cold Mix Asphalt Layer

Cold Mix Asphalt Layer Thickness (mm)	Delay (Months)
25	3
50	6

4.4. Surfacing Seals

4.4.1. Spray Seals

Spray seals consist of ordered applications of one or more bituminous products and aggregates. The proportions of component materials and rates of application are determined to ensure that the seal provides an adequate level of service. TRH3 gives guidelines on the selection of materials and application rates. Spray seals are applied on either newly constructed roads or as a reseal maintenance measure on existing roads.

In its simplest form, a spray seal consists of a coat of bituminous binder sprayed onto the road surface, which is then covered with an aggregate made up of stone, sand or grit. This aggregate cover is applied immediately after the bituminous binder has been sprayed and then rolled to ensure good contact and thus good adhesion between the aggregate and the binder coat. An example of a single seal is shown in Figure 9. Further examples of seals are given in Chapter 2: 2.3.1.2.

Surfacing Seals

The following is a comprehensive guideline for all aspects of surfacing seals:

- TRH3: **Design and Construction of Surfacing Seals**.

Various aspects of seals are discussed in:

- Chapter 2: **Pavement Composition and Behaviour**, Section 2.3.1.2
- Chapter 3: **Materials Testing**, Section 4.4
- Chapter 9: **Materials Utilisation and Design**, Section 11
- Chapter 12: **Construction Equipment and Method Guidelines**, Section 3.10
- Chapter 13: **Quality Management**, Section 7

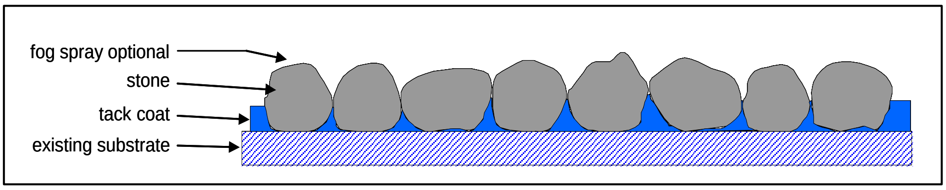


Figure 9. Single Seal

Standards set for component material properties, design, the accuracy of application and workmanship during construction have been determined though several years of experience and research. The existing design methods are based on application of the existing standards. Therefore, should standards be relaxed, the design application rates may not be appropriate.

This section provides applicable standards for surfacing seals, and where necessary, refers to other relevant sections within this document or to other relevant documents and manuals, e.g., the Standard Specifications and TRH3.

Chapter 13: 7 deals with quality control during seal construction and is particularly relevant to the application of appropriate standards during construction.

4.4.1.1. Aggregates

Aggregates of high quality should be used to achieve satisfactory performance of spray seals, especially on high volume roads. On roads carrying light traffic, consideration could be given to a relaxation of some standards.

Crushed stone aggregates for surfacing seals are a non-renewable resource. With increasing environmental pressures it is important that care be taken to utilise available aggregate fractions optimally by selecting and designing appropriate seal types.

i. Aggregate Gradings

Aggregate gradings should comply with the minimum requirements shown in Table 28.

The following guidelines are given for the selection of the grade of aggregate (1, 2 or 3), based on the binder type:

- **Modified** binders (latex modified, bitumen rubber)
  - Only grades 1 and 2
- Unmodified **penetration grade** binders
  - Only grades 1 and 2
- Unmodified **emulsion** binders
  - Grades 1, 2 and 3 aggregate.

ii. Particle Shape and Surface Texture

Aggregate shape and surface texture should comply with the requirements in Table 29. Examples of cubical and flaky aggregate are given in Figure 10.

Cubical Aggregate | **Flaky Aggregate**

Figure 10. Examples of Cubical and Flaky Aggregates

Table 28. Grading of Grade 1, 2, and 3 Aggregates

Sieve Size (mm)	Percentage by Mass Passing						
	Nominal Size (mm)						
	28	20	14	10	7.1	5	2
Grade 1 & 2							
37.5	100						
28	90 – 100	100					
20	13 – 41	90 – 100	100				
14	0 – 7	13 – 41	90 – 100	100			
10		0 – 7	13 – 41	90 – 100	100		
7.1			0 – 7	13 – 41	90 – 100	100	
5				0 – 7	13 – 41	90 – 100	100
3.35						0 – 30	
2.0					0 – 4	0 – 4	0 – 100
Grade 3							
37.5	100						
28	90 – 100	100					
20	13 – 41	90 – 100	100				
14	0 – 7	13 – 41	90 – 100	100			
10		0 – 7	0 – 58	90 – 100	100		
7.1			0 – 15	0 – 58	90 – 100	100	
5				0 – 15	0 – 58	90 – 100	100
3.35						0 – 30	
2.0					0 – 8	0 – 4	0 – 100
Fines content (passing 0.425 mm sieve)							
Grade 1	0.5	0.5	0.5	0.5	0.5	1.0	15
Grade 2	1.5	1.5	1.5	1.5	1.5	2.5	15
Grade 3	N/A	N/A	2.0	2.0	3.0	3.5	15
Dust content (passing 0.075 mm sieve)							
Grade 1	N/A	N/A	N/A	N/A	N/A	N/A	2.0
Grade 2	0.5	0.5	0.5	0.5	1.0	1.0	2.0
Grade 3	N/A	N/A	1.5	1.5	1.5	1.5	2.0

Notes

Grade 1 is recommended for highly trafficked roads, e.g., more than 1500 vehicles per day (vpd).

Grade 2 is appropriate for lower volume roads, e.g., less than 1500 vpd, when using emulsions or cut-back binders, or precoated when using straight run or hot modified binders.

Grade 3 is appropriate for low volume roads, e.g., less than 500 vpd, when using emulsions or cut-back binders, or precoated when using straight run or hot modified binders.

Table 29. Minimum Requirements for Aggregate Shape and Surface Texture

Property	Grade 1	Grades 2 and 3
Flakiness Index % (maximum)		
• 20 mm nominal size	25	30
• 14 mm nominal size	25	30
• 10 mm nominal size	30	35
• 7.1 mm nominal size	30	35
Polished Stone Value (PSV) (minimum)	50	50

iii. Hardness and Toughness

Sufficient hardness is required so that the aggregate does not crush during construction. To ensure adequate hardness and toughness, the requirements in Table 30 should be met.

Table 30. Minimum Requirements for Aggregate Crushing Strengths

Test		Grade 1, 2 and 3
Fines Aggregate Crushing Test 10% (FACT)	Dry (minimum) Wet (minimum)	210 kN 75% of dry value (=160 kN)
Aggregate Crushing Value (ACV) (%) maximum		21

Relaxation of the hardness specification can be considered for low volume roads. However, adjustments to the construction process may also be necessary. For example, the use of pneumatic rollers instead of steel wheeled rollers, to reduce crushing of aggregate particles.

iv. Durability and Soundness

The following tests may be conducted on spray seal aggregates to assess the resistance to weathering and soundness:

- Sulphate soundness test
- Freezing and thawing test
- Wetting/drying test
- Los Angeles abrasion test
- Ethylene glycol test

Current limits set for the ethylene glycol test in some contracts eliminate the use of some aggregate sources, specifically dolerites. However, seals constructed with aggregate from these sources have performed well for more than 20 years. In these situations, the advice of practitioners with extensive experience in the performance of aggregate from sources that fail the ethylene glycol test should be obtained.

v. Sand and Grit

Sand for use in spray seals should be non-plastic and free of organic matter and clay lumps. The grading of the material should comply with the requirements given in Table 31.

Table 31. Grading Requirements for Sand

Sieve Size (mm)	Percentage Passing by Mass	
	Sand	Grit
5	95 minimum	100
2	50 minimum	0 – 100
1		0 – 50
0.600		0 – 20
0.300		0 – 10
0.150		0 – 5
0.075	20 maximum	0 – 2[1]

Note:
1. Some practitioners prefer the percentage passing the 0.075 mm sieve not to exceed 1%.

Grit aggregates should be free of dust, and not contain particles greater in size than 7.1 mm. The grading of the grit should preferably lie on the coarse side of the grading given in Table 31. The sand equivalent should not be less than 35. Grit should not contain soft, weathered particles.

vi. Aggregates for Otta Seals

Normal surfacing seals use high quality single-sized aggregates, whereas Otta Seals use lower quality graded aggregates. Hence, the construction processes are slightly different. The aggregates used in Otta Seals are usually a mixture of graded aggregates, ranging from natural gravel to crushed rock. Sometimes, a sand seal cover is applied.

A large variety of materials can be used for the construction of Otta Seals since the required strength of aggregates is lower than that used for conventional spray seals. Crushed rock is the most widely used material, and, generally, if it is suitable for base material, it would be acceptable for an Otta Seal. Crushed gravel can also be used, but it may not be a viable option on smaller projects due to establishment costs.

vii. Grading and Fines Content for Otta Seals

The maximum aggregate particle size should preferably not exceed 16 mm, although 20 mm may be acceptable for the first seal in the case of double seals. The fines content (< 0.075 mm) should not exceed 10 percent. Higher fines contents may result in construction problems, as the binder tends to coat the finer particles before the large ones, resulting in a less durable surface.

The grading requirements for Otta seals as given in TRH3 are shown in Table 32.

Table 32. Grading Requirements for Aggregates for Otta Seals

Sieve Size (mm)	Percentage Passing by Mass
20	100
16	80 – 100
14	60 – 100
10	42 – 100
7.1	25 – 85
5	14 – 76
2	0 – 48
1	0 – 31
0.425	0 – 25
0.075	0 – 10

viii. Particle Shape

There is no flakiness requirement for a natural gravel or a mixture of crushed and natural gravel for Otta Seals. If crushed rock is used, it is preferable that the weighted Flakiness Index determined on the following fractions does not exceed 30:

- 10 mm to 14 mm
- 7.1 mm to 10 mm
- 5 mm to 7.1 mm

ix. Strength Requirements

Recommended strength requirements for aggregates to be used in Otta Seals are given in Table 33. Additional tests may be required for design purposes.

Table 33. Strength Requirements for Aggregates in Otta Seals

Aggregate Strength Requirements	Traffic in Vehicles per Day (vpd) at Time of Construction	
	< 100 vpd	> 100 vpd
Dry 10% FACT (minimum)	90 kN	110 kN
Wet/Dry strength ratio (minimum)	0.60	0.75

4.4.1.2. Bituminous Binders

The function of the bituminous binder in a spray seal is essentially to provide adhesion between the various aggregate particles and between the entire seal and the existing road surface. In addition, it should have sufficient cohesive strength to resist brittle fracture.

The binder viscosity should be sufficiently stable over a range of prevailing temperatures to:

- **Prevent excessive softening** up under elevated temperatures, to retain the aggregates under the action of traffic.
- **Remain flexible** at lower temperatures, to resist cracking and to accommodate flexure under the action of traffic.

The following binder related factors that influence the performance of spray seals are listed in Section 2.7.2 in TRH3:

- Binder **type** and properties
- **Grade** of binder
- Binder **application rates**
- **Viscosity** at the time of application

i. Binder Selection Criteria

A wide range of bituminous binders are used for spray seals:

- **Penetration grade bitumen:** 70/100

- **Bitumen emulsions**: cationic spray grade and polymer modified
- **Cutback bitumen:** MC-3 000
- **Modified binders**: either with synthetic polymers or rubber crumbs

TRH3 lists the following factors that influence the selection of an appropriate bituminous binder for spray seals:

- Traffic
- Climate
- Durability of binder
- Cost
- Convenience of application
- Compatibility with aggregate
- Road geometry

ii. Traffic and Climate

No fixed standards exist for selecting of binders for different climatic conditions. However, in terms of traffic and climatic criteria, recommendations from practitioners in South Africa have been collated and are shown in Table 34. It should be noted that binders other than those listed have been used successfully. Specific weather-related criteria for using cutters are covered in TRH3, Table 5-1: Recommended Binders.

Table 34. Recommended Binders for Various Traffic and Climatic Conditions

Traffic elv[1]/lane /day	Winter: Dry	Summer: Dry	Winter: Rain	Summer: Rain
< 10 000	• 70/100 pen bitumen + cutter • MC-3 000 • Emulsion (70/100 pen base bitumen) • Lowveld (70/100 pen bitumen) • Modified[2] hot binder or emulsion	• 70/100 pen bitumen • 65% emulsion (70/100 pen base bitumen) • Highveld (70/100 pen bitumen) • Modified hot binder or emulsion	• Cationic emulsion (quick setting) • MC-3 000 • Modified hot binder	• 70/100 pen bitumen + 2% cutter • Cationic emulsion • Modified hot binder
10 000 to 20 000	• 70/100 pen bitumen + cutter[3] • Modified hot binder or emulsion	• 70/100 pen bitumen • Modified hot binder or emulsion	• Modified hot binder or emulsion	• 70/100 pen bitumen + 2% cutter • Cationic emulsion • Modified hot binder
> 20 000	• Modified hot binder	• Modified hot binder	• Modified hot binder	• Modified hot binder

<u>Note:</u>

1. elv = equivalent light vehicles. One car or light delivery vehicle per lane per day. Any vehicle larger than a car or light delivery vehicle is taken to be equal to 40 light vehicles.
2. Modified bitumen refers to either homogeneous or non-homogenous polymer-modified hot binders or emulsions, specifically formulated to suit the site conditions.
3. Only petroleum based cutters (power paraffin or illuminating paraffin) should be used with bitumen.

In addition to the above guidelines, cognisance should be taken of the following:

- **Seal type**
  - Double seals with interlocking smaller aggregate or slurry, e.g., Cape seals. greatly reduce the risk of aggregate loss during, and shortly after, construction in cold periods.
  - Application of a cationic emulsion fogspray provides a bond between the "shoulders" of the aggregate, which increases the resistance against stripping.

- **Minimum temperatures:** A seal embargo during the colder months (May to August) is enforced by some road authorities, due to the risk of stripping. However, due to the different climatic conditions in South Africa, it is recommended that the minimum temperatures for the particular area are studied. Figure 11 and Figure 12 show the average minimum temperatures recorded at specific weather stations. Experience indicates that hot binders, without cutters, are sensitive to minimum temperatures below 10 °C. Therefore, if these binders are selected, the embargo period for seal work in specific areas should be adjusted.

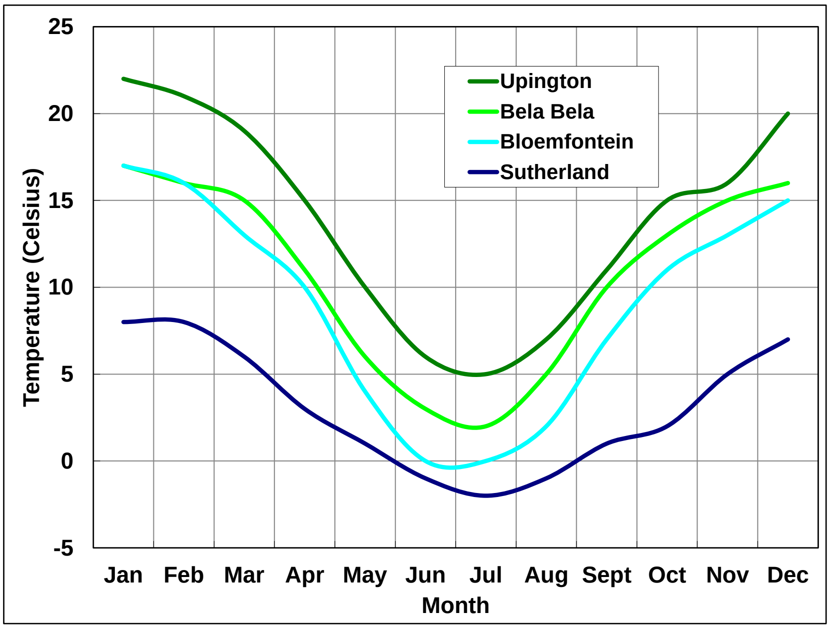


Figure 11. Example of Average Minimum Temperatures for Inland Areas

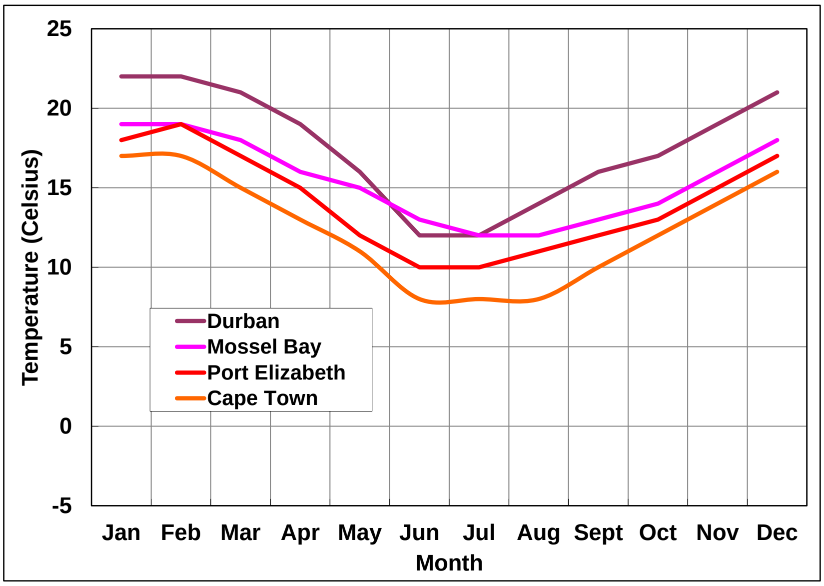


Figure 12. Example of Average Minimum Temperatures for Coastal Areas

- **Cutback binders** and **winter grade binders**.
  - Cutback binders such as MC-3 000 are less sensitive to the low temperatures experienced in some parts of South Africa. However, due to possible trapping of volatiles and resultant bleeding, the use of these binders as a **tack coat in double seals** should be avoided, specifically on high volume traffic roads.
  - Cognisance should also be taken that suppliers, without notice, could add cutters to emulsions during colder

Cutters

Only petroleum based cutters (typically illuminating paraffin) should be used with bitumen. The practice of cutting back hot binders is a hazardous process as the blending temperature of the binder is well in excess of the cutter's flash point. It is recommended that this process should only be undertaken under controlled conditions, such as at a blending plant.

If the need to blend a cutter in a sprayer on site is unavoidable, the process should only be carried out in accordance with a method statement prepared by the binder supplier.

periods. Problems could again occur due to the **trapping of volatiles**, as shown in Figure 13 where a cutback emulsion was used as the tack coat.
- Experience indicates that cutters added to modified binders take a **long time to evaporate,** minimum of 3 months). Therefore, it is advisable to use these binders only at the beginning to middle of winter, when necessary.
- In the case of a sand seal, experience has shown that MC-3 000 cutback bitumen and **sand with high silica content** performs satisfactorily, especially in drier regions.

Figure 13. Sensitivity of Geotextile Seal to Cutback Emulsion Tack Coat

- **Humidity.** High humidity, typically more than 70%, negatively affects the evaporation of volatiles or breaking of emulsion. Cases have been recorded where the emulsion required more than four days to break. Modified emulsions are particularly sensitive to these situations as "false breaking" occurs at the surface, preventing evaporation of the emulsion within the seal, as illustrated in Figure 14.

Emulsion Breaking in Seals

After the emulsion is applied to the road surface, the bitumen droplets coalesce and the water evaporates, leaving the bitumen. This is known as breaking. Typically, the emulsion is a brown colour when applied, and turns black when breaking has occurred.

It is advisable to scratch the surface of the emulsion to check that it has broken throughout the seal and not just on the surface.

Figure 14. False Break with Modified Emulsion

- **Convenience of application.** The convenience of binder application relates to the binder sensitivity and the contractor ability. Hot binders quickly cool down to the prevalent road surface temperature, reducing the ability to properly adhere to the aggregate.
  - The applicable **specification for hot binders** requires a road surface temperature during construction of 25 ^{o}C, and rising. The purpose of the rider "and rising" is to allow the contractor to start with the operation as soon as possible. However, should the surface temperature remain below 30 ^{o}C, poor adhesion could be expected.
  - Using emulsions provides the contractor with more **working hours** as the specified minimum road surface temperature is 10 ^{o}C, and rising. However, cognisance should be taken that, unless some cutters are added, the emulsion would turn back into 70/100 pen bitumen after breaking, making it sensitive to cold night temperatures.

- **Compatibility with aggregate.**
  - Initial **adhesion** between the binder and aggregate is important and depends on the properties of both the aggregate, binder and construction process. General guidelines regarding siliceous aggregates are provided in Table 35. It is always worthwhile to test the adhesion making use of either the Riedel and Weber stripping test (TMH1 Method B11) or the Modified Vialit adhesion test (Sabita Manual 15).
  - **Precoating** of aggregate and, if necessary, addition of a **wetting agent** at approximately 0.5% of the precoating fluid, could drastically improve adhesion between the aggregate and the binder. Refer to Chapter 13: 7.3 regarding the dryness of the precoated aggregate before application.
  - Aggregates with **high silica content**, such as quartzite, sandstone, granite have poor adhesion with some bituminous products, especially in the presence of moisture. For this reason, cationic emulsion should be used with these aggregates.
  - **Basic (non-siliceous)** aggregates perform satisfactorily with penetration grade bitumen, cutback bitumen, anionic or cationic bitumen emulsions. In view of the minimal difference in cost between cationic and anionic spray grade bitumen emulsions, as well as for practical considerations, cationic emulsion is normally used.
  - For **sand seals,** MC-3 000 cutback bitumen performs satisfactorily with high silica content sand, especially in drier regions.

Table 35. Binder-Aggregate Combinations

Suitability of Binder-Aggregate Combination		
Binder Type	**Siliceous Aggregate**	**Non-Siliceous Aggregate**
Penetration bitumen	No	Yes
MC-3 000 cutback bitumen	No	Yes
Cationic bitumen emulsion	Yes	Yes

- **Road Geometry**. Steep slopes of the road surface, arising from road gradients or superelevation, could cause binder run-off during construction. Recommended maximum gradients for various types of binder are given in Table 36 from Table 5-2 in TRH3.

Table 36. Recommended Maximum Gradients or Super-Elevations for Application of Binder Types

Binder Type	Maximum Slope[1]
Modified hot binder Bitumen grade: 70/100 pen	12% 10%
Cutback bitumen: MC-3 000	 8%
Emulsions: 60% 65%	 6% 8%

Notes:
1. The values of maximum slope given above are guidelines only, and are dependent on factors such as road surface temperature, texture and permeability of the existing surface and experience and competency of the applicator.

4.4.2. Bituminous Slurry Seals and Microsurfacing

Bituminous slurry seals and micro-surfacings comprise a mixture of graded aggregates, emulsified bituminous binder and active filler. The gradings of micro-surfacing mixes are usually coarser than those of slurries. A modified bitumen emulsion binder is normally used.

4.4.2.1. Aggregates

The crusher sand used in slurry seals should have the following properties:

- Produced from **parent rock**
- Maximum **ACV** of 30%
- Minimum **sand equivalent** of 30
- The Standard Specifications stipulates that up to 25% of **clean natural sand** may be added, and the sand equivalent of the aggregate blend is a minimum 35.

The purpose of adding natural sand is to:

- Improve **workability**
- Reduce the **water demand**

- Obtain a suitable **flowable consistency**
- Reduce **cost** due to less crusher sand being **hauled** over long distances.

Balling

Instead of the slurry consisting of a flowable mixture with a creamy consistency, the bitumen emulsion forms balls as it prematurely breaks around the finer aggregate fractions.

The requirements given in TRH3 allow up to 50% sand in the aggregate blend if a cationic stable grade bitumen emulsion is used, or an adhesion agent is added. However, it is essential that the mixture of sand be tested with different emulsion contents as described in Sabita Manual 28. This is to ensure there is sufficient binder to prevent ravelling, without the mix being too fatty, i.e., high binder content. Typically when rounded natural river sand of more than 25% is added, the range of appropriate emulsion contents becomes very small.

The purpose of testing the sand equivalent is to reduce the risk of balling, especially if the percentage of finer fractions is high, the material has some plasticity and temperatures during construction are high.

In addition, the purpose of the slurry should be evaluated before standards are relaxed. For example, a slurry texture treatment or a 10 mm Cape seal on a temporary bypass only need to last a few months at most.

Table 37 gives the gradings of various slurry mixtures. For rapid setting slurries, the fine slurry (medium) and fine slurry (coarse) gradings are used, and a proprietary product is added to speed up the setting. The fine slurry (medium) grading is sued for overlays 6 to 8 mm thick. The fine slurry (coarse) grading is used for rut filling, where a thicker layer is required. The grading for slurries used for texture improvement only are also given in Table 37.

Table 37. Aggregate Gradings for Slurries

Sieve Size (mm)	Percentage Passing by Mass					
	Fine Slurry (Grade)			Coarse Slurry		Texture Improvement
	Fine	Medium	Coarse	Type 1	Type 2	
14					100	
10				100	86 – 100	
7.1		100	100	87 – 100	71 – 91	
5	100	84 – 100	72 – 92	72 – 92	62 – 82	
2	84 – 99	51 – 90	40 – 64	40 – 63	36 – 56	100
1	60 – 90	33 – 68	25 – 46	22 – 41	22 – 41	95 – 100
0.600	42 – 72	22 – 50	19 – 34	15 – 30	15 – 30	82 – 100
0.300	23 – 48	15 – 37	12 – 25	10 – 20	10 – 20	50 – 70
0.150	10 – 27	7 – 20	7 – 18	6 – 15	6 – 15	20 – 35
0.075	4 – 12	4 – 12	2 – 8	4 – 10	4 – 10	7 – 15

Continuously graded aggregate is important to ensure stability and to prevent segregation. The grading envelopes recommended in Table 37 have been tested and adjusted over many years to ensure good performing slurries. Standards could however, be adjusted provided the mixes are tested in the laboratory (Refer SABITA Manual 28).

4.4.2.2. Active Fillers

Cement used in slurry should be Portland cement complying with SANS 50197-1. Slaked lime complying with SANS 824 is also used as active filler in bituminous slurries. A maximum of 1% to 1.5% of lime, by mass of dry aggregate, may be added to improve workability, prevent segregation and to assist with breaking of the emulsion.

4.4.2.3. Water

As a rough guide, 160 litres of water per cubic metre of dry aggregate should be added to obtain an appropriate flow. This amount does however, depend upon the type of aggregate and prevailing temperatures on site, with more water being required on hot days. Cognisance should be taken that the water will evaporate, leaving interconnected voids through which water could enter into the base. The water demand is typically 80% of the emulsion content. If the water demand exceeds the emulsion content, alternative aggregates should be investigated. The pH requirements of the water used are included in Table 38. When the total dissolved solids count of the water is greater than 500 ppm, the water should be tested for compatibility with the emulsion.

Table 38. Requirements for Water used in Bituminous Slurries

Bitumen Emulsion Type Used in the Slurry	pH Requirements
Anionic	7 to 9
Cationic	4 to 7

4.4.2.4. Bitumen Emulsion

The types of bitumen emulsion extensively used in South Africa are:

- **Stable grade anionic emulsion** manufactured with 70/100 penetration grade bitumen in summer and addition of up to 3% cutter in winter
- **Stable grade cationic emulsion** manufactured with 70/100 penetration grade bitumen in summer and addition of up to 3% cutter in winter
- **Spray grade cationic emulsion** manufactured with 70/100 penetration grade bitumen
- **Quick setting cationic emulsion**
- **Quick setting modified cationic emulsion**

Hot Climates

In hot climates it is recommended that 70/100 penetration grade bitumen be used in the manufacture of all the bitumen emulsions.

Specifications related to emulsions are covered in Section 4.1.

4.5. Primes, Precoating Fluids and Tack Coats

This section addresses standards applicable to primes, stone precoating fluids and tack coats. Figure 15 shows the application of a tack coat.

Figure 15. Application of a Tack Coat

References for Primes, Precoating Fluids and Tack Coats

These materials are covered in this manual in the following sections:

- Chapter 3, **Materials Testing,** Section 4.5
- Chapter 9, **Materials Utilisation and Design**, Section 7
- Chapter 12: **Construction Equipment and Method Guidelines**, Section 3.9
- Chapter 13, **Quality Management**, Section 7.3.4.

Further information on standards that apply to primes and stone precoating fluids can be found in Sabita Manual 26, as well as in the Standard Specifications, while there is reference to the use of tack coats in Sabita Manuals 5, 22 and 27.

4.5.1. Primes

4.5.1.1. Standard Primes

The primes most widely used in the construction of roads include:

- MC-30 or MC-70 cutback bitumen grades complying with SANS 4001-BT2.
- Inverted bitumen emulsion complying with SANS 4001-BT5.

4.5.1.2. Proprietary Products

Proprietary products that do not comply with SANS specifications are also used. In this case, the supplier should provide specifications against which the product can be tested for compliance. These specifications should meet the following requirements:

Coal Tar Based Primes and Precoating Fluids

These primes are prohibited as they introduce carcinogenic hazards, which are **harmful to health** and pose serious **contamination** threats to the environment.

- **Distillation test** (ASTM D402): Minimum residue from distillation of 50% of the total volume
- **Penetration test** (ASTM D5): Penetration at 25 °C of the residue should be between 90 and 180 dmm

Bitumen emulsion based primes, known as "Eco-primes", have been developed which are more environmentally friendly than the cutback primes, with solvent contents around 50% less than those used in MC-30.

> **Emulsion or Diesel as Precoating Fluid**
> The use of bitumen emulsion or diesel has, in most cases, been found to be unsuitable for use as precoating fluid.

Blending of primes to reduce their viscosities should be carried out in a proper blending facility, where proper health and safety precautions can be implemented, and not on site. The heating of the cutback primes should be carried out as soon as practical before spraying, to reduce the loss of the volatile fractions. Typical application rates for primes are covered in Chapter 9: 7.1.9.

4.5.2. Stone Precoating Fluids

Precoating fluids consist of low viscosity bitumen based products containing petroleum cutters and a chemical adhesion agent. Their purpose is to precoat surfacing aggregates to improve the adhesion of the aggregate to the bituminous binder. The precoating fluid should contain at least 0.5% of a chemical adhesion agent. Specifications for bitumen-based precoating fluids are given in Table 39. Typical application rates for precoating fluids are covered in Chapter 9: 7.2.4.

Table 39. Specification for Bituminous-Based Precoating Fluid

Property	Requirement
Density @ 25°C, kg/ℓ	0.85 – 0.95
Saybolt Furol viscosity @ 50 °C, SF	10 – 30
Distillation to 360 °C , v/v% to:	
190 °C	0 – 15
225 °C	10 – 55
260 °C	45 – 75
316 °C	70 – 95
Residue from distillation to 360 °C, v/v%	45 – 50
Dynamic viscosity @ 25 °C of residue distilled to 360 °C (cps)	300 – 500
Stripping number (Riedel & Weber)	Report[1]

Note:
1. This test should be carried out to assess the effectiveness of precoating on the aggregate and binder to be used on a particular project. Tests should therefore be carried out on the aggregate with and without precoating.

4.5.3. Tack Coats

A tack coat is a bituminous product that is applied either on top of a primed granular base or between layers of asphalt, its function being to promote adhesion. Tack coats are also used to enhance adhesion along transverse and longitudinal joints in asphalt layers. A tack coat is needed before applying a microsurfacing on an existing bituminous surfacing. Tack coats consist of anionic/cationic and modified/unmodified bitumen emulsion. Typically bitumen emulsion is diluted 1:1 with water when used as a tack coat. However some road authorities require the undiluted emulsion to be used, in which case the application rate is reduced. Details of typical application rates are given in Chapter 9: 7.3.4.

4.6. Bitumen Stabilized Materials (BSM)

Bitumen stabilized materials are covered in TG2, "A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilized Materials". The section contains pertinent information on standards relevant to these materials, but the reader is referred to TG2 which covers this subject in great detail.

> **Bitumen Stabilization**
>
> The following is a comprehensive guideline for all aspects of BSMs:
>
> - **TG2** (2009), Second Edition: Technical Guideline: Bituminous Stabilised Materials – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials.
>
> Various aspects of bitumen stabilization are discussed in:
>
> - Chapter 2: **Background**, Section 2
> - Chapter 3: **Materials Testing**, Section 4.6
> - Chapter 9: **Materials Utilisation and Design**, Section 9
> - Chapter 10: **Pavement Design**, Section 7
> - Chapter 12: **Construction Equipment and Method Guidelines**, Section 3.5 and 4.6
> - Chapter 13: **Quality Management**, Section 5

4.6.1. BSM Classification

BSMs are divided into three classes in TG2, depending on the quality of the parent material, design traffic and the position in the pavement, as follows:

- **BSM1**. High shear strength material, typically used as a base layer for design traffic exceeding 6 MESA. The parent material for this class is typically a well graded crushed stone or reclaimed asphalt.
- **BSM2**. Moderately high shear strength material, generally used as a base layer for traffic less than 6 MESA. The parent material would generally be a graded natural gravel with or without reclaimed asphalt.
- **BSM3**. The parent material of this class typically consists of soil-gravel and/or sand. As a base layer it is only suitable for design traffic of less than 1 MESA.

The requirements for the three classes are based on the level of mix design being carried out. TG2 differentiates between levels of design as follows:

- **Level 1 mix design**, in which 100 m diameter specimens are prepared for ITS testing. The aim is to identify the preferred bitumen stabilizing agent, determine the optimum binder content and identify the need for the use of a filler.
- **Level 2 mix design**, which uses 150 mm diameter specimens for ITS tests. The aim is to optimise the binder content.
- **Level 3 mix design**, in which triaxial and moisture induced sensitivity (MIST) testing is done for a higher confidence level.

> **BSMs**
>
> Chapter 3: 4.6 outlines the most important test methods used for BSMs, while all material properties and test methods are referenced or described in detail in TG2.

The requirements for the various ITS tests and triaxial test parameters (friction angle, cohesion and retained cohesion) in terms of the BSM classes are given in Table 40.

Table 40. Requirements for BSM

Test	Specimen Diameter	BSM Class		
		BSM1	BSM2	BSM3
ITS_{dry}	100 mm	> 225	175 - 225	125 - 175
ITS_{wet}	100 mm	> 100	75 - 100	50 - 75
TSR	100 mm	Note 1		
ITS_{equil}	150 mm	> 175	135 - 175	95 - 135
ITS_{soaked}	150 mm	> 150	100 - 150	60 - 100
Cohesion (kPa)	150 mm	> 250	100 - 250	50 - 100
Friction angle (°)	150 mm	> 40	35 - 40	< 30
Retained cohesion (MIST) %	150 mm	> 75	60 - 75	50 - 60

Note:

1. Where TSR < 50% it is recommended that an active filler be used. Where, in addition, the ITS_{dry} > 400 the material is likely to contain clay, and bitumen would be largely ineffective. In such cases, pre-treatment of the material should be considered. Refer to Section 4.4.1 of TG2.

4.6.2. Component Materials

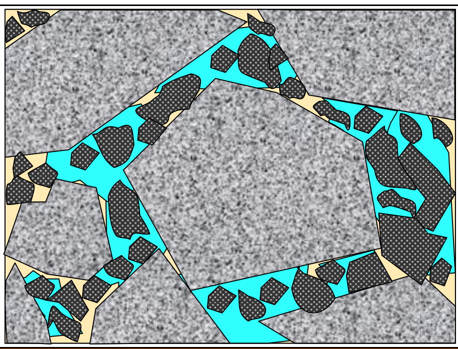
A range of materials have been stabilized successfully using either foamed bitumen or bitumen emulsions. Examples of materials stabilized with bitumen are:

- **Crushed stone** (normally G1 – G3): all rock types.
- **Natural gravels** (normally G4 – G6): derived from parent materials such as andesite, basalt, chert, diabase dolerite, dolomite, granite, limestone, norite, quartz, sandstone and pedogenic materials such as ferricrete/laterite.
- **Reclaimed pavement layers** either consisting of reclaimed asphalt blended with some underlying crushed stone or gravel layer material, or previously stabilized crushed stone and/or gravel.

4.6.2.1. Grading

The nature of dispersion of the bitumen in BSMs varies significantly in BSM-foam and BSM-emulsion. As illustrated in Figure 16, in BSM-foam, the dispersed bitumen droplets only partially coat the large aggregate and the mastic consisting of filler, bitumen and water "spot welds" the coarser aggregate fractions together. In a BSM-emulsion material more extensive coating of the larger aggregate particles by the bitumen occurs. Consequently the aggregate grading requirements for the two types of binders are slightly different, with BSM-foam requiring a higher percentage of fines than BSM-emulsion.

The general grading requirements for both BSM-foam and BSM-emulsion are indicated in terms of zones of ideal and less suitable aggregate composition in Table 41. Gradings falling within the "less suitable" range should only be utilised where alternatives are severely limited or extremely costly. Where feasible, aggregates should be blended with missing fractions to improve their grading. In general, coarse graded materials require less bitumen than finer graded materials.


BSM-Emulsion

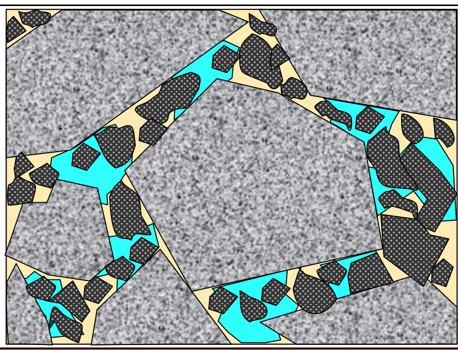

BSM-Foam

Figure 16. Bitumen Dispersion in BSMs

Table 41. Recommended Gradings for BSMs

Sieve Size (mm)	Percentage Passing			
	BSM-Emulsion		BSM-Foam	
	Ideal	Less Suitable	Ideal	Less Suitable
50	100		100	
37.5	87 – 100		87 – 100	
28	82 – 100	100	82 – 100	100
20	72 – 100	100	72 – 100	100
14	60 – 90	89 – 100	60 – 90	89 – 100
10	51 – 77	77 – 100	51 – 77	77 – 100
7.1	42 – 65	65 – 100	42 – 65	65 – 100
5	36 – 57	57 – 96	36 – 57	57 – 96
2	22 – 40	40 – 76	22 – 40	40 – 76
1	16 – 32	31 – 63	16 – 32	31 – 63
0.600	12 – 27	27 – 54	14 – 28	28 – 54
0.425	10 – 24	24 – 50	12 – 26	26 – 50
0.300	8 – 21	21 – 43	10 – 24	24 – 43
0.150	3 – 16	16 – 30	7 – 17	17 – 30
0.075	2 – 9	9 – 20	4 – 10	10 – 20

4.6.2.2. Durability

The potential durability of the untreated granular material is assessed in terms of its resistance to breakdown and generation of excessive plastic and non-plastic fines by means of the Durability Mill Index (DMI) (See Chapter 3: 2.9). The recommended limits for various aggregate types are shown in Table 42.

4.6.2.3. Reclaimed Asphalt (RA)

Recycling projects sometimes require the reuse of RA in excess of 75% of the total mix before blending with additional materials. In such cases, the quality of the RA needs to be carefully considered in the mix design in terms of:

- Traffic
- Climatic region
- Axle load
- Composition of the RA

For more detail, the reader is referred to TG2.

4.6.2.4. Filler

Filler material used with BSMs can be classified into two categories; active and natural. Active fillers alter the mix properties chemically, whereas as natural fillers essentially alter the particle size distribution (or grading) of the material.

i. Active filler

This category covers materials such as:

- **Cement:** Various types but excluding rapid hardening types. An example of cement being spread on a road before recycling with foamed bitumen or emulsion is shown in Figure 17.
- **Hydrated lime**
- **Fly ash**
- **Slagment**

Cement Contents in BSMs

It is not recommended that more than 1% cement is included in BSMs. And, the cement content should not exceed the binder content.

Table 42. Durability Mill Index Limits

<table>
<tr><th>Rock and Soil Group</th><th>Aggregate Type</th><th>DMI Limit</th></tr>
<tr><td>Acid crystalline</td><td>Granite
Gneiss
Rhyolite</td><td rowspan="4">< 420</td></tr>
<tr><td>High silica</td><td>Hornfels
Quartzite</td></tr>
<tr><td>Carbonate</td><td>Dolomite
Limestone</td></tr>
<tr><td>Metalliferous</td><td>Ironstone
Magnesite
Magnetite</td></tr>
<tr><td>Pedogenic</td><td>Calcrete
Ferricrete
Silcrete</td><td>< 480</td></tr>
<tr><td>Arenaceous</td><td>Sandstone
Siltstone
Conglomerate</td><td rowspan="3">< 125</td></tr>
<tr><td>Diamictite</td><td>Greywacke
Tillite</td></tr>
<tr><td>Argillaceous</td><td>Mudrock
Phyllites
Shale</td></tr>
<tr><td>Basic crystalline</td><td>Basalt
Dolerite
Gabbro</td><td>< 100</td></tr>
</table>

The purpose of incorporating active filler in BSM is to:

- Improve **adhesion** of the bitumen to the aggregate
- Aid the **dispersion** of the bitumen, particularly for BSM-foam
- Modify the **plasticity** of the natural materials, i.e., reduce the PI
- Increase the **stiffness** of the mix and rate of **strength gain**
- Accelerate **curing** of the compacted mix
- Control the **breaking time** of BSM-emulsion
- Improve the **workability** of BSM-emulsion, in some cases

The application rate of active filler is typically 1% by mass of dry aggregate. At higher levels of active filler, the increase in mix stiffness significantly compromises the flexibility of the material. Above these application rates, the benefit of the bitumen is hardly realized. It is also recommended that the active filler content does not exceed the binder content.

ii. Natural filler

The addition of natural filler primarily supplements the fines required for adequate bitumen dispersion.

Figure 17. Spreading Cement to be Mixed into Recycled Materials

4.6.2.5. Anti-Stripping Agents

The emulsifiers used in bitumen emulsions, e.g., amines in cationic emulsions, also serve as anti-stripping agents, so no additional anti-stripping agents are applied with BSM-emulsions.

Where BSM-foam is used in wet regions or moderate regions with poor drainage, it is advisable to treat the bitumen with an appropriate anti-stripping agent. Under favourable conditions, the addition of 1% by mass of suitable active filler may suffice. However, if flexibility is sought from the foamed bitumen treated layer, an amine-type anti-stripping agent should be considered. Between 0.2 and 2% by mass of such agents are usually applied to the bitumen before foaming, allowing sufficient time for blending. In such cases, the foam characteristics should be rechecked, as these can be altered by the amines.

4.6.2.6. Water

The quality of the water used to create the foam and the emulsion is important to ensure a mix of reliable quality. The Standard Specifications should be followed.

4.6.2.7. Bituminous Binder

Penetration grade bitumen is used to produce foamed bitumen and emulsion for the manufacture of BSM-foam and BSM-emulsion. The types of binders and binder requirements are outlined below.

i. Bitumen Emulsion

Binders with penetration values between 70 and 100 are generally selected for emulsion production, although softer and harder binders are used successfully. Anionic or cationic stablemix 60% emulsions are used almost exclusively for BSMs in South Africa. This grade of emulsion is formulated for maximum mix stability and therefore renders the binder suitable for use with dense graded aggregates or materials with a high fines content. Furthermore, extended workability periods are afforded to ensure good dispersion of the binder.

The selection of emulsion class for stabilization is influenced by the type of aggregate. The guidelines outlined in Table 43 indicate that certain aggregates are not suitable for stabilization with anionic emulsions. These aggregates have silica contents above 65% and alkali contents below 35%, i.e., acidic rocks. In such cases, a cationic emulsion should be used.

Table 43. Compatibility of Emulsion Type with Aggregate Type

Aggregate Type	Compatible With	
	Anionic Emulsion	Cationic Emulsion
Dolerite	✓	✓
Quartzite	✗	✓
Hornfels/Greywacke	✓	✓
Dolomite	✓	✓
Granite	✗	✓
Andesite	✓	✓
Tillite	Variable	✓
Basalt	✓	✓
Sandstone	✗	✓
Rhyolite	✗	✓
Marble/Norite	✓	✓
Syenite	✗	✓
Amphibolite	✓	✓
Felsite	✗	✓

ii. Foamed Bitumen

Binders with penetration values between 70 and 100 are generally selected for BSM-foam. Softer and harder bitumen are used successfully, although harder bitumen is generally avoided because of poor foam quality.

The penetration value alone does not assure suitability of a particular grade of bitumen for use in a foamed bitumen mix. The foaming properties of candidate bitumen grades need to be tested and assessed on the basis of the Expansion Ratio and Half-life as described in TG2. These tests will be published as SANS 3001-BSM1. Foamed bitumen is illustrated in Figure 18.

Foam Characteristics

The **expansion ratio (ER)** is the maximum volume of foam relative to the original volume.
The **half-life ($\tau_{1/2}$)** is the time the foam takes to collapse to half of its maximum volume.

Figure 18. Foamed Bitumen

5. Standards for Cementitious Materials

This section includes the various standards applied to cementitious materials. The standards covered in this section of Chapter 4 are closely related to Chapter 3: 5 and Chapter 9: 6. Frequent reference is made to these sections.

Standards for cementitious materials cover:

- **Concrete**, reinforcing steel, joint sealants, as well as the materials used in concrete.
- **Concrete blocks**, materials used in their manufacture, bedding and jointing sand, construction of concrete block pavements.
- **Stabilization** using cementitious materials, including standards applicable to materials after stabilization, stabilizing agents such as lime and cement, and standards for the natural materials before stabilization.

References for Cementitious Materials

Cementitious materials are covered in this manual in the following sections:

- Chapter 2, **Pavement Composition and Behaviour**
  - Section 2.1 and 4.2
- Chapter 3, **Materials Testing**
  - Section 5, Tests on Cemented materials
- Chapter 6, **Road Prism and Pavement Investigations**
  - Section 7.4.1.1, Identification of Cemented Pavement layers
  - Section 8, Materials Testing for Investigations
- Chapter 8, **Material Sources**
  - Section 2, Project Quarries and Borrow Pits
  - Section 3, Commercial Material Sources
- Chapter 9, **Materials Utilisation and Design**
  - Section 6, Pavement Layers: Cementitious
  - Section 12, Concrete
  - Section 13, Block Paving
- Chapter 10, **Pavement Design**
  - Section 7, Structural Capacity Estimation: Flexible Pavements
  - Section 8, Structural Capacity Estimation: Concrete Pavements
  - Section 9, Structural Capacity Estimation: Concrete Block Pavements
- Chapter 12: **Construction Equipment and Method Guidelines**
  - Section 3.4, 3.12 and 3.13, Construction Process Guidelines
  - Section 4, Trial Sections
- Chapter 13, **Quality Management**
  - Section 5, Pavement Layers: Cemented
  - Section 7, Concrete
  - Section 8, Block Paving
- Chapter 14, **Post-Construction**
  - Section 4, Distress

5.1. Concrete

The main components of concrete include crushed stone, sand, cement and water. Various extenders and admixtures are used to enhance properties of the concrete, while curing compounds are used to improve curing conditions once the concrete has been poured or paved. Often, steel reinforcing is used to provide tensile strength in structural concrete and to control cracking in concrete pavements. Joint sealants are used to seal formed joints in concrete pavements. This section, which covers standards applicable to all these materials as well as standards for the hardened concrete, should be read in conjunction with Chapter 3: 5.1.8.2.

5.1.1. Aggregates Used in Concrete

Aggregates are used in concrete to make it more dimensionally stable and to also reduce its cost. Standards for aggregates used in concrete are contained in SANS 1083. Other useful information on the quality of aggregates used in concrete can be found in:

- Fulton's Concrete Technology (2009)
- C & CI's Concrete Road Construction (Perrie and Rossmann, 2009)
- The Standard Specifications

The most important properties, and standards, are summarised in Table 44 (fine aggregates), and Table 45 and Table 46 (coarse aggregates).

Fine and Coarse Aggregates

Fine: Sand of particle size such that at least 90% passes 5 mm sieve size and is retained on the 0.075 mm sieve.
Coarse: Stone with particle sizes retained on the 5 mm sieve.

Table 44. Important Requirements for Fine Aggregates

Property	Fine Aggregate
Grading	• Not less than 90% shall pass the 5 mm sieve • Between 5% and 25% shall pass the 150 µm sieve
Fineness modulus (FM)	• Between 1.2 to 3.5. • Where FM is specified by the purchaser, the actual value shall not differ from the specified value by more than 0.2
Dust content	• Material passing 0.075 mm shall not exceed 5% • 10% permissible for aggregate from mechanically crushed or milled rock[1]
Clay content, material of particle size smaller than 5 µm mass (%)	2.0 maximum
Methylene blue adsorption value	0.7 maximum
Chloride content (percent by mass of CL^-)	Shall not exceed: • Sand for prestressed concrete: 0.01 • Sand for normal reinforced concrete: 0.03 • Sand for non-reinforced concrete: 0.03
Organic impurities	The colour of the liquid above the fine aggregate shall not be darker than the colour of the reference solution, unless the fine aggregate complies with the requirements for soluble deleterious impurities.
Presence of sugar	Free from sugar unless the fine aggregate complies with the requirement for soluble deleterious impurities.
Soluble deleterious impurities	Compressive strength of the mortar bar made with the sand shall develop compressive strength of not less than 85% of that of a mortar bar made with the same sand after thorough washing. This requirement is only applicable to fine aggregates derived from the natural disintegration of rock, and is then only mandatory if tests for organic impurities and/or sugar indicate that this is necessary.

Notes:
1. Certain provisos in SANS 1083 allow the dust content of fine aggregates to be increased if other criteria are met.

Table 45. Grading Requirements for Coarse Aggregate

Sieve Size (mm)	Nominal Size of Aggregate (mm)							
	75.0	**50**	**37.5**	**28**	**20**	**14**	**10**	**7**
75.0	100	100						
50	0 – 43	70 – 85	98 – 100					
37.5	0 – 25	0 – 50	85 – 100	100				
28	0 – 7	0 – 28	15 – 55	90 – 100	100			
20		0 – 7	0 – 28	15 – 55	90 -100			
14			0 – 7	0 – 28	15 – 55	90 – 100	100	
10				0 – 7	0 – 28	15 – 55	90 – 100	100
7.1					0 – 9	0 – 30	25 – 58	92 – 100
5						0 – 7	0 – 28	15 – 55
2							0 – 4	0 – 28
1								0 – 4

Table 46. Other Properties of Coarse Aggregates

Property	Coarse Aggregate
Dust content, percentage by mass of material passing 0.075 mm sieve	2 maximum
10% FACT	The test is carried out on the minus 14 mm plus 10 mm fraction and shall not be less than: • Stone for concrete subject to abrasion 110 kN (dry) • Stone for concrete not subject to abrasion 70 kN (dry)
ACV[1]	ACV (dry) shall not exceed 29%
Flakiness Index	Maximum 35%

Note
1. ACV is optional alternative to 10% FACT

There are several other properties of coarse aggregates used in concrete that are not specified in Table 46, but are listed in SANS 1083.

Drying shrinkage requirements for both the fine and coarse aggregates are specified in the Standard Specifications. This specification, which includes requirements for the shrinkage of the concrete itself, is mentioned later in Section 5.1.9 for hardened concrete. The Standard Specifications also includes criteria for alkali reactivity of concrete aggregates.

5.1.1.1. Aggregates for Concrete Pavements

Other aggregate properties in addition to those in SANS 1083 that are considered important for aggregates used in the construction of concrete pavements include:

- **Drying shrinkage** of the fine aggregate
- **Alkali reactivity**

The maximum size of coarse aggregate is often limited for one or more reasons. In the case of concrete in structures, the maximum size of aggregate should be limited to 25% of the minimum section thickness or to 50% of the minimum spacing between reinforcing bars, whichever is less.

In the case of concrete pavements, the **nominal maximum size** of coarse aggregate should be limited to one quarter of the pavement thickness. In practice, therefore:

- **Nominal 20 mm coarse aggregate** is suitable for pavement thicknesses between 100 and 150 mm
- **Nominal 28 mm aggregate** for thicknesses between 150 and 175 mm
- **Nominal 37.5 mm aggregate** for thicknesses greater than 175 mm
- **Nominal 37.5 mm aggregate** should be combined with a smaller size, e.g., 20, 14, or 10 mm, in accordance with the recommendations of an approved concrete testing laboratory.
- In special circumstances, **nominal 20 mm or 28 mm aggregate** may also require blending with a smaller aggregate.

The **fineness modulus** (see Chapter 3: 2.3.3) of the fine aggregate should not deviate from the approved material by more than 0.20. If this occurs, the mix may have to be redesigned. Variations in fineness modulus have a significant effect on the workability of concrete and this can create problems, particularly with slipform paving.

The **fine aggregate** should possess an acid insolubility of at least 40% for skid resistance. This requirement is satisfied when quartzitic sand is used. Calcareous sands, such as dolomite, are acceptable if blended with at least 40% of suitable quartzitic sand.

Choosing Cement
When choosing cement for use in concrete pavements, the type of pavement, as well as the environment in which it will be constructed, should be taken into account. Of prime importance is adequate early strength gain for joint cutting as well as adequate abrasion resistance.

5.1.2. Standards for Cement and Cement Extenders

5.1.2.1. Cement

Cement shall comply with the requirements of SANS 50197-1. Note that it is illegal to sell common cement in South Africa without a regulatory Letter of Authority (LOA) number from the National Regulator for Compulsory Standards, which indicates compliance with SANS 50197-1 or EN 197-1. This specification is not referred to in the existing Standard Specifications, but identifies various "products in the family of common cements" based on their constituents, extenders and the relative proportions of these. The classification of the current cement types is summarised in Table 47 and Table 48. A typical cement would now be identified as, for example, CEM II B-V 32.5 R. This describes a Portland-fly ash cement containing 65 – 79% of clinker and 21 – 35% of fly ash, with a strength class of 32.5 MPa. The R indicates an early strength requirement. All testing of cement shall conform to the requirements of SANS 50196 Parts 1 to 7.

Selling Cement
It is illegal to sell common cement in South Africa without a regulatory Letter of Authority (LOA) number from the National Regulator for Compulsory Standards which indicates compliance with SANS 50197-1 or EN 197-1.

Despite this nomenclature being widely publicised, and all cement sold using the classification, it is not uncommon to still see the specification of Ordinary Portland Cement (OPC) for road stabilization projects in tender documents and Bills of Quantities. OPC is currently a brand name of a cement from one supplier, and is not necessarily the best choice for stabilization of road materials.

The full specifications are given in SANS 50197-1 and all cement sold must have a Letter of Authority certifying compliance. However, cements deteriorate with time and if the cement is suspected to be too old, testing for compliance with SANS 50197-1 shall be ordered.

Table 47. Cement Strength Classes

Strength Class	Compressive Strength (MPa)			
	Early Strength		Standard Strength	
	2 days	7 days	28 days	
32.5 N	–	≥ 16.0	≥ 32.5	≤ 52.5
32.5 R	≥ 10.0	–		
42.5 N	≥ 10.0	–	≥ 42.5	≤ 62.5
42.5 R	≥ 20.0	–		
52.5 N	≥ 20.0	–	≥ 52.5	–
52.5 R	≥ 30.0	–		

5.1.2.2. Cement Extenders

Cement extenders are materials used with Portland cement, and must never be used on their own. Cement extenders are incorporated into various cements as is evident in Table 48. Cement extenders can also be blended together with cement on site.

The three commonly used cement extenders are:

- **Ground granulated blast furnace slag (GGBS)** is a by-product from the blast furnace used in the production of iron. The molten slag is quenched in water, and then milled to a fine powder.
- **Fly ash (FA)** is collected from flue gases of furnaces fired with pulverised coal and is classified into coarse and fine fractions. The fine fraction is used as a cement extender, while the coarse fraction is either used for other industrial purposes or as an aggregate.
- **Condensed silica fume (CSF)** is an extremely fine substance formed by the condensation of vapour from the ferrosilicon smelting process.

Cement extenders should comply with the requirements of Parts 1, 2 and 3 of SANS 1491.

Cement Deterioration

Cements deteriorate with time and if the cement is suspected to be too old, testing for compliance with SANS 50197-1 shall be ordered.

Table 48. Classification of Cements According to SANS 50197-1

Main Types	Notation of products (types of common cement)		Composition (percentage by mass)										
			Clinker	Blast Furnace Slag	Silica Fume	Pozzolana		Fly Ash		Burnt Shale	Limestone		Minor Additional Constituents
						Natural	Natural Calcined	Siliceous	Calcareous				
			K	S	D	P	Q	V	W	T	L[1]	LL[1]	
CEM I	Portland cement	CEM I	95 – 100	–	–	–	–	–	–	–	–	–	0 – 5
CEM II	Portland-slag cement	CEM II A-S	80 – 94	6 – 20	–	–	–	–	–	–	–	–	0 – 5
		CEM II B-S	65 – 79	21 – 35	–	–	–	–	–	–	–	–	0 – 5
	Portland-silica fume cement	CEM II A-D	90 – 94	–	6 – 10	–	–	–	–	–	–	–	0 – 5
	Portland-pozzolana cement	CEM II A-P	80 – 94	–	–	6 – 20	–	–	–	–	–	–	0 – 5
		CEM II B-P	65 – 79	–	–	21 – 35	–	–	–	–	–	–	0 – 5
		CEM II A-Q	80 – 94	–	–	–	6 – 20	–	–	–	–	–	0 – 5
		CEM II B-Q	65 – 79	–	–	–	21 – 35	–	–	–	–	–	0 – 5
	Portland-flyash cement	CEM II A-V	80 – 94	–	–	–	–	6 – 20	–	–	–	–	0 – 5
		CEM II B-V	65 – 79	–	–	–	–	21 – 35	–	–	–	–	0 – 5
		CEM II A-W	80 – 94	–	–	–	–	–	6 – 20	–	–	–	0 – 5
		CEM II B-W	65 – 79	–	–	–	–	–	21 – 35	–	–	–	0 – 5
	Portland-burnt shale cement	CEM II A-T	80 – 94	–	–	–	–	–	–	6 – 20	–	–	0 – 5
		CEM II B-T	65 – 79	–	–	–	–	–	–	21 – 35	–	–	0 – 5
	Portland-limestone cement	CEM II A-L	80 – 94	–	–	–	–	–	–	–	6 – 20	–	0 – 5
		CEM II B-L	65 – 79	–	–	–	–	–	–	–	21 – 35	–	0 – 5
		CEM II A-LL	80 – 94	–	–	–	–	–	–	–	–	6 – 20	0 – 5
		CEM II B-LL	65 – 79	–	–	–	–	–	–	–	–	21 – 35	0 – 5
	Portland-composite cement	CEM II A-M	80 – 94	6 – 20									0 – 5
		CEM II B-M	65 – 79	21 – 35									0 – 5
CEM III	Blast furnace cement	CEM III A	35 – 64	36 – 65	–	–	–	–	–	–	–	–	0 – 5
		CEM III B	20 – 34	66 – 80	–	–	–	–	–	–	–	–	0 – 5
		CEM III C	5 – 19	81 – 95	–	–	–	–	–	–	–	–	0 – 5
CEM IV	Pozzolanic cement	CEM IV A	65 – 89	–	11 – 35					–	–	–	0 – 5
		CEM IV B	45 – 64	–	36 – 55					–	–	–	0 – 5
CEM V	Composite cement	CEM V A	40 – 64	18 – 30	–	18 – 30	–	–	–	–	–	–	0 – 5
		CEM V B	20 – 39	31 – 50	–	31 – 50	–	–	–	–	–	–	0 – 5

Note
1. For limestone, the L class may not exceed 0.5% by mass of limestone, and LL may not exceed 0.2% by mass of limestone.

5.1.3. Standards for Mixing Water

In general, water used in concrete should be clean and free from detrimental concentrations of acids, alkalis, salts, sugar and other organic or inorganic substances that could impair the setting time, durability or strength of the concrete or any reinforcing steel or dowels in the concrete.

Potable water can be considered suitable for use in concrete; water that is acceptable for human consumption would not need to be subjected to testing.

If there is any doubt as to the quality of the water, it should be tested for compliance with SANS 51008/EN1008 "Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete". Some pertinent requirements of this standard are presented in Table 49. Table 26 in Chapter 13: 8.1.3 of SAPEM gives further information on water for concrete.

Table 49. Requirements for Mixing Water

Maximum Chloride Content	
End Use of Concrete	**Maximum Chloride Content (mg/ℓ)**
Prestressed concrete or grout	500
Concrete with reinforcement or embedded steel	1 000
Concrete without reinforcement or embedded steel	4 500
Harmful Substances	
Substance	**Maximum Content (mg/ℓ)**
Sugars	100
Phosphates (P_2O_5)	100
Nitrates (NO_3 -)	500
Lead (Pb^{2+})	100
Zinc (Zn^{2+})	100
Sulphates (SO_4^{2-})	2 000

In cases where alkali-reactive aggregates are expected to be used in the concrete, the water should be tested for its alkali content. In this case, the equivalent sodium oxide content of the water should not exceed 1500 mg/ℓ. Should this value be exceeded, the water may only be used if it is shown that other preventative measures can be implemented to prevent deleterious alkali-silica reactions.

5.1.3.1. Setting Time

The initial setting time of specimens made with the unknown water should not be less than one hour and should not differ by more than 25% from the initial setting time obtained on specimens made using distilled or de-ionised water. The final setting time should not exceed 12 hours and should not differ by more than 25% from the final setting time of specimens made using distilled or de-ionised water.

5.1.3.2. Strength

The mean strength at 7 days of the concrete or mortar specimens, prepared with the water, should be at least 90% of the mean compressive strength of the replicate specimens prepared with distilled or de-ionised water.

5.1.4. Standards for Chemical Admixtures

Admixtures are chemicals which are added to concrete at the mixing stage to modify some of the mix properties. Admixtures should never be regarded as a substitute for good mix design, good workmanship, or use of good materials.

The use of admixtures in design and construction of concrete is covered in Chapter 9: 12.4.2.4, while a chapter is devoted to admixtures in Fulton's Concrete Technology, 9th edition. Admixtures are normally categorized according to their effect:

- Plasticizers (water-reducing agents)
- Superplasticizers
- Air entrainers
- Accelerators

- Retarders
- Others

Many admixtures provide combinations of properties such as plasticizer and retarder or plasticizer and air entrainer. Chemical admixtures should conform to the requirements of ASTM C494 and air-entraining admixtures to the requirements of ASTM C260. The European EN 934 standard is also used for some admixtures.

Admixtures containing any form of chloride should not be permitted in concrete having any steel including reinforcement, stressing cables, tiebars, dowels or hold-down bolts.

Admixtures Containing Choride
Admixtures containing any form of chloride should not be permitted in concrete having any **steel** including reinforcement, stressing cables, tiebars, dowels or hold-down bolts.

5.1.5. Standards for Curing Compounds

Curing compounds for concrete pavements should be white-pigmented resin-based curing compound which comply with the requirements of ASTM C309. They should be tested in accordance with BS 7542 and the efficiency index should exceed 90% at an application rate of 0.2 ℓ/m^2. Wax-based compounds, those containing water or in emulsion form, should not be used as they are generally less effective and unlikely to meet the efficiency requirements. Compounds for use in structures should be chosen to ensure durability requirements are met.

5.1.6. Standards for Reinforcing Steel

Reinforcing bars should comply with the relevant requirements of SABS 920. Welded steel fabric should comply with the relevant requirements of SABS 1024.

5.1.7. Standards for Jointing Materials

Joint fillers for expansion or isolation joints should be of the closed-cell polyethylene foam type complying with AASHTO M153. Joint sealing material should be a one-component, low-modulus silicone sealant complying with the requirements of the Standard Specifications.

5.1.8. Standards for Fresh Concrete

The various test methods used to measure the consistency of fresh concrete are covered in Chapter 3: 5.1.8.1. However, for completeness the recommended test methods are shown in Table 50.

Table 50. Applicable Test Methods for Various Levels of Concrete Workability

Concrete Level of Workability	Applicable Test Method
Very low	Vebe time
Low	Vebe time, Compaction factor
Medium	Compaction factor, Slump
High	Compaction factor, Slump, Flow
Very high	Flow

Tolerances for concrete consistency using these tests, as given in BS EN 206–1 are shown in Table 51.

Table 51. Tolerance for Concrete Consistency Determined by the Various Tests

Value (mm)	**Slump**		
Target	≤ 40	50 – 90	≥ 100
Tolerance	± 10	± 20	± 30
Time (seconds)	**Vebe Time**		
Target	≥ 11	10 – 6	≤ 5
Tolerance	± 3	± 2	± 1
Value	**Degree of Compaction (Compaction Index)**		
Target	≥ 1.26	1.25 – 1.11	≤ 1.10
Tolerance	± 0.10	± 0.08	± 0.05
Value (mm)	**Flow Diameter**		
Target	All values		
Tolerance	± 30		

Tolerances given in SANS 878 for ready-mixed concrete, which specifies slump tolerances for concrete for a period of 30 minutes from arrival at the job site, are shown in Table 52. For air-entrained concrete, the allowable tolerance for the air content is ± 1.5%.

Table 52. Tolerances for Slump and Air Content of Ready-Mix Concrete

Specified Slump (mm)	Tolerance (mm)
50 or less	– 15 to + 25
More than 50, up to 100	± 25
More than 100	± 40

Slump ranges for various types of construction are specified in the Standard Specifications, and shown in Table 53. A picture of the slump test is shown in Figure 19.

Figure 19. Slump Test

Table 53. Slump Values Specified in the Standard Specifications

Type of Construction	Slump (mm)	
	Minimum	Maximum
Prestressed concrete	25	75
Concrete nosings and prefabricated units	50	75
Mass concrete	25	100
Reinforced concrete walls, footings, cast in situ piles (except dry-cast piles), slabs, beams and columns	50	125

In the case of concrete used in the construction of road pavements, the consistency requirements vary depending upon the type of paving equipment used, and the following slump values are recommended:

- **Slipform paving:** Slump 10 mm to 50 mm, but the Vebe tests is generally preferred to the slump test.
- **Fixed form paving:** Concrete slumps in the range of 20 mm to 70 mm are usually suitable.
- **Manually operated fixed form paving:** Slumps in the range of 50 mm to 100 mm are recommended.

The Standard Specifications specifies a maximum water:cement ratio of 0.53, as well as a minimum cement content of 320 kg/m^3 for concrete used in concrete road pavements.

5.1.9. Standards for Hardened Concrete

Several standards applicable to hardened concrete are covered in this section, including strength, shrinkage, durability and alkali-silica reactivity.

5.1.9.1. Strength

The most commonly specified property of hardened concrete is cube strength. The class of concrete is indicated by the characteristic 28 day cube compressive strength and the nominal size of the coarse aggregate in the mix. For example, Class 30/38 concrete means concrete with a characteristic compressive strength of 30 MPa after 28 days, and a nominal coarse aggregate size of 38 mm.

The characteristic cube compressive strength may be any strength from 15 MPa, in increments of 5 MPa, up to 60 MPa, those usually specified are 15, 20, 25, 30, 40, 50 and 60 MPa.

SANS 2001-CC1 includes statistical methods for assessing the results of tests carried out on cubes. The Standard Specifications also specifies methods for assessing cube compressive strength results. The strength of concrete can also be assessed from the drilling and testing of core specimens. The results of compressive strength tests carried out on cores are assessed for acceptance or rejection in accordance with SANS 101200 (clause 14.4.3.1).

Flexural strengths are specified for concrete that is subjected to bending, for example in concrete road pavements. In this case, the following specifications should be followed:

- **Minor roads**. Specify a target flexural strength of not less than 4.0 MPa at 28 days. Generally, a characteristic 28 day compressive strength of 30 MPa will satisfy this flexural strength requirement unless rounded alluvial pebbles are used in the concrete mix.
- **Major roads**. The concrete should meet the strength requirements in the Standard Specifications. The 28 day compressive strength is determined from laboratory mixes. The specified compressive strength shall be the highest of the following four values:
  - 35 MPa at 28 days
  - 0.85 fc_1, where fc_1 is the 28 day compressive strength corresponding to that of a mix with a 28 day flexural strength of 4.5 MPa
  - 0.85 fc_2, where fc_2 is the 28 day compressive strength of a mix with a water:cement ratio of 0.53
  - 0.85 fc_3, where fc_3 is the 28 day compressive strength of a mix with a cement content of 320 kg/m^3

5.1.9.2. Shrinkage

The shrinkage of concrete can be measured using SANS 6085. The Standard Specifications require the test to be carried out at three water:cement ratios and specifies a maximum shrinkage of 0.04%. The same limit for shrinkage is specified in SANS 2001–CC1. This requirement may be difficult to achieve in some coastal areas with sedimentary aggregates, where a maximum shrinkage of 0.06% may be more attainable. The validity of this test is questionable as it is carried out in a desiccation oven and does not simulate shrinkage of concrete in a structure.

Shrinkage Tests
The validity of this test is questionable as it is carried out in a dessiciation oven and does not simulate shrinkage of concrete in a structure.

5.1.9.3. Durability

The chapter on durability in Fulton's Concrete Technology's contains a wealth of useful information. Table 54 includes recommendations for concrete exposed to the atmosphere.

Table 54. Recommendations for Concrete Exposed to the Atmosphere

Concrete Specification	Type of Environment			
	Non-polluted	Polluted	Corrosive	Highly Corrosive
Minimum cement content (kg/m^3)	As dictated by strength requirements	340	380	420
Cement type	Any cement complying with SANS 5017-1 70% CEM I + 30% FA 50% CEM I + 50% GGBS			
Maximum water:cement	As dictated by strength requirements	0.55	0.50	0.45
Minimum cover to steel (mm)	25	30	40	50
Minimum strength	As per structural requirements			

5.1.9.4. Alkali-Silica Reactivity

The Standard Specification requirements for the total alkaline content (Na_2O-equivalent) are discussed in Section 5.1.1.

5.2. Concrete Block Paving

Modern segmental block pavements are manufactured to close dimensional tolerances and are paved on layers where modern compaction and quality control methods assure suitable support. These pavements are bedded on a relatively thin layer of bedding sand and jointed together with fine-grained sand. Blocks are also used to stabilize and protect embankments, bare not used for river protection.

The following documents provide information on requirements for concrete paving blocks and supplementary paving materials:

- UTG2
- CMA publications
- The Standard Specifications
- SANS 1200 MJ

Block types refer to the plan shape of the block, whether interlocking using types S-A or S-B, or, non-interlocking using type S-C. Concrete paving blocks should be fully interlocking and comply with the requirements of SANS 1058. See Chapter 9: 13.1.2 for illustrations of the different block types.

Concrete Block Paving

Block paving is discussed in the following chapters of SAPEM:

- Chapter 3, **Materials Testing,** Section 5.2
- Chapter 9, **Materials Utilisation and Design**, Section 13
- Chapter 10, **Pavement Design**, Section 9
- Chapter 12, **Construction Equipment and Method Guidelines**, Section 3.18 and 4.8
- Chapter 13. **Quality Management**, Section 9

5.2.1. Constituent Materials for Concrete Blocks

5.2.1.1. Cement

The cement should comply with the requirements of SANS 50197–1. If extenders are used they should comply with the requirements of SANS 1491–1, SANS 1491–2, and SANS 1491–3.

5.2.1.2. Aggregates

Aggregates should comply with the requirements of SANS 1083.

5.2.1.3. Water

The water used in the manufacture of the concrete should be free from impurities that might impair the strength or durability of the concrete.

5.2.1.4. Pigments

Pigments used for colouring the concrete should comply with the requirements of EN 12878. SANS 1058 specifies the shape, appearance, colour, and surface texture of the concrete blocks. Dimensions are specified in terms of linear dimensions and cross-sectional squareness. Tolerances for the block sizes are given in Table 55.

Table 55. Tolerances for Concrete Blocks

Dimension	Tolerance (mm)
Length	± 2
Width	± 2
Height	± 3

The cross-sectional squareness of the block measured, according to SANS 1058, at any point along the perimeter of the block, should not vary by more than 2 mm.

5.2.2. Tensile Splitting Strength

The strength of concrete blocks is specified in SANS 1058 in terms of tensile splitting strength. Average and individual values are given in Table 56. The test is illustrated in Figure 20.

Test Methods

The test methods for **tensile splitting strength**, **abrasion resistance**, as well as **water absorption**, are covered in Chapter 3: 5.1.8.

Table 56. Tensile Splitting Strength of Concrete Blocks

Strength Class	Tensile Splitting Strength (MPa)	
	Average	Individual
1	2.2	1.8
2	2.8	2.3

Figure 20. Tensile Splitting Strength Test

5.2.3. Abrasion Resistance

The average and individual mass loss of blocks determined shall not exceed 12 g and 15 g respectively.

5.2.4. Water Absorption

The average and individual water absorption of blocks should not exceed 6.5% and 8.0% respectively.

5.2.5. Bedding and Jointing Sand

Bedding and jointing sand should be free of substances that may be deleterious to the concrete blocks. The required grading of the bedding sand is given in Table 57.

Table 57. Grading Requirement for Bedding Sand

Sieve Size (mm)	Percent Passing
10.0	100
5	96 – 100
2.0	72 – 96
1.0	40 – 76
0.600	25 – 60
0.300	10 – 30
0.150	5 – 15
0.075	0 – 10

Sands

Mine sands as well the fine sands found on the **Cape Flats** and in the **Port Elizabeth** area are generally acceptable as bedding sand.

Jointing sand should pass through the 1.0 mm sieve, and 10 – 50% should pass the 0.075 mm sieve. the Standard Specifications specify that 10 – 15% should pass the 0.075 mm sieve.

5.2.6. Construction Standards for Block Paving

The subgrade and subbase should be constructed in accordance with SANS 1200 DM and SANS 1200 ME. Requirements for the construction of concrete block pavements are also covered in the Standard Specifications. Edge restraints consisting of kerbs or channels, or other edge strips, should be constructed on the subbase before any concrete block units are laid.

Bedding sand, with a moisture content 6% ± 2%, should be evenly screeded over the subbase, to achieve a compacted thickness of 25 ± 10 mm. Checks on smoothness should conform to the requirements of SANS 1200M. Tolerances for various items are given in Table 58.

Table 58. Tolerances of Various Items

Item	Tolerance [1] (mm)
Units as manufactured	
• Deviation of length from nominal length	± 2
• Deviation of width from nominal width	± 2
• Deviation of depth (or thickness) from nominal depth (or thickness)	± 3
• Deviation of squareness, measured as specified in SANS 1058	± 2
Foundation layers	
• Deviation of top subbase layer from designated level	± 10
• Smoothness of top subbase layer measured on a 3 m straight line in any direction	± 10
• Thickness of 25 mm compacted sand bedding layer	± 10
Finished paving: The finished surface of the paving shall, 3 months after opening to traffic, be accurate to the following limits:	
• Line of pattern	
– Deviation of any 3 m straight line, maximum	10
– Deviation from any 20 m straight line, maximum	20
• Vertical deviation from 3 m straight line	
– At kerbs, channels, gullies, manholes and other edge restraints	0 to 3
– Elsewhere, subject to adjustment where necessary for vertical curve	10 to 15
• Surface levels at adjacent units, difference not to exceed	3
• Deviation of finished level from designated level	10 to 15

Note:
1. Tolerances listed are for Degree of Accuracy I, the highest. For Degrees of Accuracy II and III the specifications are contained in the project specification.

5.3. Stabilization Using Cementitious Materials

5.3.1. Standards for Cementitious Stabilizing Agents

Stabilization of materials using cementitious stabilizing agents is common practice in South Africa. The most regularly used products are cement and hydrated lime.

In the past, stabilization of road materials using Ground Granulated Blast Furnace Slag (GGBS) previously referred to as milled blast furnace slag and fly ash (FA), usually with the addition of lime, has been carried out. With the new generation of cements available, GGBS and FA are blended with the cement at source and it is unusual to use these materials individually on site, as they usually required blending with other materials, specifically lime, to activate their pozzolanic properties.

In cases where on-site blending of these materials is still considered, the Standard Specifications precludes the use of GGBS on its own as a stabilizing agent and requires it to be blended either with cement or lime to form cement-slag or cement-lime stabilizing agents.

It should be noted that not all of the cements identified in Table 48 are produced in South Africa. In fact, many of these cements are very geographic specific, which must be taken into account when planning any stabilization project. The stabilization design must be based on the cement likely to be available for the project. It should also be noted that the production and properties of cements can change fairly rapidly over time. Long delays between laboratory stabilization designs and construction can result in the same cement not being available any longer.

Stabilizing with Lime

All limes used for road stabilization should be slaked lime. Unslaked (quick) limes are available but have serious health hazards when used on site and are not recommended.

Various stabilizers are available for the improvement of materials that do not meet the standards required.

5.3.1.1. Lime

Lime for road stabilization can be calcium lime, magnesium lime or dolomitic lime. All limes used for road stabilization shall be slaked lime. Unslaked (quick) limes are available but have serious health hazards when used on site and are not recommended. They could, however, be used in certain circumstances to dry excessively moist clayey material, to assist workability.
Lime shall comply with the requirements of SANS 824 and bear the SABS mark. To comply with SANS, the following requirements shall be met:

- **Calcium and magnesium oxides** content shall exceed 75% (by mass)
- Ratio of available **lime** to total lime shall exceed 0.65
- **Carbon dioxide** content shall not exceed 5%
- Combined **water in slaked limes** shall not be less than 13%

In addition, the particle sizes of the lime shall comply with Table 59.

Table 59. Particle Size Requirements of Slaked Lime (SABS 824)

Type of Lime	Fineness	
	Sieve Size (mm)	Percentage Retained (max)
Quicklime	2	0.5
Slaked lime	0.85 0.60 0.075	0 2.5 25.0

5.3.2. Standards for Cementitiously Stabilized Materials

5.3.2.1. Classification of Cementitiously Stabilized Materials

TRH14 classifies cementitiously stabilized materials as:

- Cemented **crushed stone** or gravel (C1 or C2)
- Cemented **natural gravel** (C3 and C4)

The main elements of this classification are summarised in Table 60.

Some road authorities apply additional and more stringent standards to cementitiously stabilized materials, such as those given in Table 61. In this table, additional standards are included, amongst others, for Indirect Tensile Strength and wet/dry durability.

It is becoming common practice to specify crushing and/or screening of G5 and G6 materials used in the construction of C3 and C4 stabilized layers. In these cases, some road authorities require the grading of these materials to comply with those of G4 quality materials.

5.3.2.2. Standards for Processing Cementitiously Stabilized Pavement Layers

The following maximum continuous periods from the time the stabilizing agent comes into contact with the layer that is to be stabilized, until the completion of compaction, are recommended:

- **Cement** or cement blends 6 hours or as determined from working time test (Chapter 3, Appendix A2)
- **Slaked lime** 10 hours
- **Unslaked lime** 10 hours

Some road authorities have, however, reduced these periods to less than 6 hours for cement and cement blends. Temperature limitations are also specified. The working time should preferably be determined for each material, cement type and climate using the method in Chapter 3, Appendix A.2. No stabilization is allowed with:

- **Falling air temperatures,** when the air temperature falls below 7 °C
- **Rising air temperatures**, when the air temperature is below 3 °C

Table 60. TRH14 Classification of Cementitiously Stabilized Materials

Class	C1	C2	C3	C4
Material Class Before Stabilization	**G2**	**G2/G3/G4**	**G5/G6**	**G5/G6**
Aggregate Quality Before Stabilization				
Grading (Sieve size, mm)	**Nominal Maximum Size of Aggregate (percent passing)**			
	38 mm	**28 mm**		
38	100		Maximum size in place after compaction should not exceed two thirds of the compacted layer thickness, or 63 mm, whichever is the smaller.	
28	90 – 100	100		
20	75 – 95	85 – 95		
14	65 – 85	71 – 84		
5	48 – 62	45 – 64		
2	41 – 53	27 – 45		
0.425	30 – 47	13 – 27		
0.075	5 – 12	5 – 12		
Crushing strength ACV (max) or 10% FACT (min)	29% 110 kN		Not applicable	
Flakiness Index	Max 35%		Not applicable	
Sand Equivalent	Max 30% for any sand added to correct the grading		Not applicable	
Design Strength of Stabilized Materials				
Class	**C1**	**C2**	**C3**	**C4**
Unconfined compressive strength: (UCS in MPa) at 7 days, 100% MDD	Min 6 Max 12	Min 3 Max 6	Min 1.5 Max 3.0	Min 0.75 Max 1.5
Atterberg Limits after Stabilization	Not applicable		Max 6	

Table 61. Additional Standards for Cementitiously Stabilized Materials

Classification	C1	C2	C3	C4
Material before treatment	At least G2 quality	At least G4 quality	At least G5 quality	At least G6 quality
PI after treatment	Non-plastic	Non-plastic	6 max [1]	6 max [1]
UCS (MPa) [2]	6 min	4 min	1.5 min	0.75 min
ITS (kPa) [3]	–	–	250 min	200 min
Wet/dry durability (% loss) [4]	5 max	10 max	20 max	30 max

Notes:
1. For materials derived from the basic crystalline rock group, the Plasticity Index after stabilization shall be non-plastic.
2. Unconfined Compressive Strength @ 100% MDD.
3. Indirect tensile Strength @ 100% MDD.
4. Wet/Dry Durability according to SANS 3001-GR55.

UCS and ITS Commentary

Two properties are currently used to measure the effectiveness of the stabilizing agent: UCS and ITS. Current specifications contain a conflict between the minimum ITS and the UCS range required.

Beware of adding too much stabilizer to fine grained materials to achieve acceptable ITS values, resulting in UCS, values exceeding upper UCS limits. When good quality materials are stabilized, a low percentage passing the smaller sieve sizes can result in high UCS values. Experience has shown that, dependent on stabilizer and soil type, the rough relationship between ITS and UCS can vary from 1:7 to 1:15.

6. STANDARDS FOR OTHER MATERIALS

6.1. Waste and By-Product Materials

Many millions of cubic metres of by-product and waste materials are available in South Africa on waste dumps, tailings disposal facilities, landfills and various other storage facilities. These materials have typically passed through at least one industrial process, e.g., crushing, burning and separation, resulting in a relatively processed material with a high embodied energy content. The use of such materials in road construction has a number of benefits, including energy, environmental and social spin-offs. However, their nature (many are extremely fine grained) and possible properties (inclusion of soluble salts, acids and unstable components) make many of these materials unattractive to road engineers, despite their potential economic and environmental benefits. Before using such materials, it should, be confirmed that the material cannot be recycled into a higher value material. An example is broken glass, which may be more economically and environmentally beneficial when recycled into new glass than used in road construction.

Proprietary and Certified Products

Various aspects of proprietary products are discussed in:

- Chapter 3: **Materials Testing**, Section 6
- Chapter 8: **Materials Sources**, Section 4
- Chapter 9: **Materials Utilisation and Design**, Section 14
- Chapter 13: **Quality Management**, Section 10

Agrément South Africa, the certification body for proprietary products, is discussed in Chapter 3: Section 6.3.

When using such materials in road construction, a good understanding of their properties and potential problems is necessary before they can be considered as substitutes for conventional non-renewable construction materials. The optimum requirements for these types of materials would be that they conform to the standard specifications described previously in this Chapter for soils, gravels and aggregates. To confirm this, each material should be classified as an equivalent of a soil, gravel or aggregate, and the relevant properties should be identified.

Any material that complies with the project specification, usually the Standard Specification, in terms of the properties listed can be used without hesitation, provided that any other potential problems are identified and considered:

- Grading
- Atterberg Limits
- Strength
- Particle shape
- Durability
- Soluble salt contents
- Deleterious materials

The existing specifications usually state that the material shall be derived from natural gravel or crushed rock, which may effectively exclude many recycled materials; this should be addressed in the project specifications. South Africa currently has no standard specifications for non-conventional materials, primarily because each material probably has specific properties that need to be controlled individually. Typical problems that can be expected include, but are not limited to:

- Time dependent **durability** problems, e.g., the slow slaking of residual magnesium oxide (periclase) in slags while in service as a result of hydration, with excessive volume increases
- High water or bitumen **absorptions** in more porous materials
- High **solubilities**
- Potential to **leach** into the environment

To identify potential problems, it is very important to understand the nature, method of formation and the physical and chemical properties of such materials.

Many of the so-called waste or "by product" materials have unusual properties and their use can only be investigated during laboratory and/or full-scale testing. A typical example of this is the use of broken glass, which is brittle and usually

Use of Waste/By-Product Materials

Before a waste or by-product material is used, it should be classified as a soil, gravel or aggregate. Then, relevant standards for that classification must be met.

flaky, in asphalt. Up to 15% of conventional aggregate can safely be replaced by screened broken glass. It should be remembered that waste glass should preferably be re-used in glass production rather than as an aggregate, to conserve the latent energy and production inputs as far as possible.

Essentially, almost any waste material can be used somewhere in the road prism, with spin-off environmental benefits, such as minimising materials in waste dumps. However, it is essential to identify the nature of the material, and any potential problems, whether the material complies with existing material requirements as specified in this document, and, whether it is cost-effective to use without unacceptable risk. The fact that waste materials are used internationally, and various reports on their use are available, indicates that more consideration should be given to using them in South Africa. However, most of these materials will require specific, and often unique, standards that need to be included in the project specifications.

The most common waste materials that have potential for use in road construction are discussed in the following sub-sections.

6.1.1. Construction and Demolition Waste

Construction and demolition waste is a potentially good construction material, although it too, can have inherent problems that need to be understood. These include:

- Material **variability**, particularly in terms of density and water absorption
- Presence of **unsuitable materials**, e.g., plastic and wood
- Excessive quantities of **"soft" materials**, e.g., gypsum board and mortar

These materials have usually already been in service for an extended period. They comprise mostly processed materials, baked bricks or ceramics, uncarbonated and carbonated cement, sand and aggregate, which are generally stable and unlikely to be affected by conventional aggregate durability problems. The materials are usually non-plastic, and deterioration of their constituents will not increase the plasticity. Breaking down of softer materials will usually lead to filling of voids, densification and decreased permeability, all beneficial to the overall pavement behaviour, within limits. Depending on the initial degree of compaction, however, some rutting may be evident. An example of a demolition waste stockpile is shown in Figure 21. Construction and demolition waste is discussed in Chapter 8: 4.4.

Figure 21. Demolition Waste Stockpile

6.1.2. Slag, Ash and Mine Waste

Slag, ash and mine waste are also potential construction materials. Examples are shown in Figure 22, Figure 23 and Figure 24. The dominant problems associated with slag, ash and mine waste are usually related to the presence of soluble salts or high sulphide contents. The existing standards take these into account, but it is possible to make use of such materials with adequate precautionary measures (Netterberg, 1979; Roads Department, 2001). Many of these products may also have low particle strengths that need to be assessed, and precautions or corrective action taken.

Pre-processing of such material prior to use can improve their properties significantly. This normally requires exposure of the material to atmospheric and moist conditions. Spreading the materials out in thin layers some time prior to processing for use, possibly with periodic mixing, can often allow the hydration, oxidation, reaction and leaching of unstable components. Slags, and examples of their use in South Africa, are discussed further in Chapter 8: 4.5. Fly ash and mine waste are discussed in Chapter 8: 4.6 and 4.7.

Figure 22. Mountain of Slag from Iscor, Pretoria

Figure 23. Ash, Used to Construct Pavement near Cullinan, Gauteng

Figure 24. Old Mine Dump Used as Source for Crushed Stone

6.1.3. Other Useful Waste Materials

Other waste materials, e.g., fly ash, bottom ash, incinerator ash, phosphogypsum and mine slimes, need to have their properties assessed individually and potential uses based on their compacted strengths identified. Their particle size distributions would normally exclude them as conventional layer materials. However, their self-cementing or stabilization properties may allow their use, either on their own or when blended, with other natural or waste materials.

6.2. Non-Traditional Chemical Stabilizers

During the last three decades or so, there has been a proliferation of non-conventional soil stabilizers on the market. These products are marketed with the promise of extraordinary improvements in the quality of unsuitable or marginal materials and range in cost from very low to extremely high. It must be clearly stated that, other than those products based on and including traditional stabilizers (cement, bitumen, and lime), none of the proprietary chemical stabilizers currently marketed produce strengths equivalent, or even close to, those produced by the conventional soil stabilizers. No specific standards for these products are currently available in South Africa. However, depending on their application, they could be required to comply with existing standards for natural or stabilized materials.

Two types of non-traditional soil chemical additives are generally available. The first is essentially a dust suppressant, which has minimal influence on the strength of the materials to which they are applied. The other is specifically targeted at the improvement of material strength and is probably of greater importance in sealed road construction. This is because the products are often quite costly and when used in unsealed roads, although slowing down gravel loss, will still be lost with time. Sealing retains their benefits for longer.

6.2.1. Dust Suppressants (Fines Retention)

A number of available non-traditional soil additives are marketed with the specific objective of treating the upper layers of unsealed roads to reduce dust, and often have an additional benefit of reducing gravel loss. They can also be useful for the reduction of dust on construction sites and/or deviations. An example of a road that has a dust suppressant applied is shown in Figure 25.

Figure 25. Road with Dust Palliative

Dust palliatives include primarily lignosulphonates and chloride based product:

- **Lignosulphonates** are produced as a residue from the wood pulping industry, and are effective binders of fine particles. When applied to unsealed roads with a relatively wide variation in properties, they can be highly effective in reducing dustiness as well as giving an added benefit of reducing gravel loss and maintenance requirements through what is essentially a gluing action. They are, however, highly water soluble and are thus rapidly leached from the road surface during the wet season. Fortunately, they are most effective, and needed, during the dry season, when road dust is at its worst.

- **Chloride based products** are primarily calcium and magnesium, although sodium is sometimes included. The effectiveness of these products is a function of their hygroscopic or deliquescent properties, i.e., their ability to absorb moisture from the atmosphere and retain the road surface in a slightly moist condition. This suppresses dust generation under traffic. They are also highly soluble in water, and thus leached out of the road with time. These products are only likely to be successful when the minimum relative humidity in the area is in excess of 50%, for the majority of the time.

Repeated application of both of these generic products is necessary.

> **Dust Suppressants**
>
> There are currently no standards for these materials, with each supplier having their own internal "recipes" and standards. Their use should thus be accompanied by a Product Performance Guarantee (PPG) from the Supplier. The PPG should include a definition of the degree of dust reduction, the effective time over which this will occur and possibly any maintenance benefits that will accrue. The PPG must be agreed between the parties involved.

There are currently no standards for these materials, with each supplier having their own internal "recipes" and standards. Their use should thus be accompanied by a Product Performance Guarantee (PPG) from the Supplier. The PPG should include a definition of the degree of dust reduction, the effective time over which this will occur and possibly any maintenance benefits that will accrue. The PPG must be agreed between the parties involved. The effectiveness of these products on individual materials is best assessed through localised trial sections.

Certain physical and chemical information regarding the products is usually provided on the Material Data Safety Sheets, which can be used as a simple guide to the quality of the product provided. The supplier should be requested to provide the data sheets.

The use of any dust palliative should be in accordance with a strict maintenance programme, involving the correct timing of maintenance and rejuvenation activities. Any conventional routine maintenance activities, e.g., grader blading or spot regravelling should be cleared with the supplier before being carried out.

The use of dust palliatives should be considered when:

- It is evidently **uneconomical to apply a bituminous surfacing**, even after life cycle cost comparisons.
- There are definite **traffic safety issues** due to dusty conditions.
- It is established that the **dust damages the environment**.

6.2.2. Soil Stabilization

The use of proprietary chemical products as soils stabilizers is less understood than their use as dust palliatives. There is a much wider range of products, with little scientifically supported marketing, and little information on the reaction mechanisms of many of the products. Many of these proprietary soil additives promise significant increases in the strength of the soil materials after treatment. The products cover a wide range of raw materials, including sulphonated oils, enzymes and polymer emulsions. The ingredients and processes used in their manufacture are wide and varied. Handling and storage conditions should be ascertained from the suppliers. Many of the products have restricted shelf lives. The quality of any product that has been in storage for more than 3 months should be referred to the supplier, for confirmation of its continued acceptability for use.

As in the case of the dust suppressants, there are no standards for these proprietary chemicals. Each manufacturer has their own "recipe" which appears to change on a frequent basis, as do the names of many of the products. Those materials accredited by a body such as the Agrément Board require that manufacture of the product conforms to an in-house quality control system and that all product sold shall be consistent and within the standards of the company. There is, however, little that the end-user can do to confirm the quality other than to assess the information provided by the manufacturer on delivery of the additives. Reference to the Material Safety Data Sheet may also provide some limits for specific properties of the material.

There is, however, definite local and international evidence that some of the chemicals can be effective. However, little is known about the life cycle costs, and thus, overall cost-effectiveness of the majority of the products. It is recommended that some form of Product Performance Guarantee system is agreed between the product supplier and the end-user.

6.2.2.1. Types of Stabilizer

The proprietary soil stabilizer types can be generically grouped, as shown in Table 62. This table also shows the type of improvement in soil properties that can be expected, as well as the types of material for which soil compactibility may be improved.

Table 62. Proprietary Soil Stabilizer Types

Additive Type	Suitability Assessment			
	Soil Compactibility	Strength Improvement	Volume Stability	Waterproofing
Ionic	Fine grained soils	Low – medium	Low – medium	Low – medium
Enzyme	Fine grained soils	Low	Low – medium	Low
Petroleum resins	Granular soils	Medium	Medium	High
Polymers	Granular soils	Medium – high	Medium	Medium high
Others[1]	Granular soils	High – very high	High	Medium – very high

Notes:
1. These include products that may contain cement, lime and/or bitumen

6.2.2.2. Actions/Reactions of Stabilizers

There is considerable debate regarding the actions of many of these stabilizers. The following reflect general consensus on the action/reactions of stabilizers.

- **Ionic stabilizers,** which include the sulphonated petroleum products, are generally accepted as undergoing an ionic exchange reaction with suitable clay minerals and/or attaching to the adsorbed water as a result of the hydrophilic nature of the ionic portion of the chemical. It is well known that clay minerals have a surface charge, typically negative, which attracts the "double layer" water that affects the properties of the clay minerals. The actions of the ionic soil stabilizers result in a decrease in the double layer water and an improvement in the properties of the treated material. This has been observed in the field and proven in the laboratory (Paige-Green, 2002).
- **Enzymes** apparently act as catalysts only and accelerate a bonding reaction between organic and inorganic soil components, according to a number of suppliers. The construction techniques and application rates, however, are similar to those for ionic stabilizers, and it is considered that base materials may contain similar active components.
- **Petroleum resins** are not widely used in South Africa, but appear to be derived from natural petroleum resin, a tacky aromatic hydrocarbon derived from crude oil, emulsified with water. The mechanism of these products is to glue the soil particles together.
- **Polymers** are gaining acceptance as stabilizers, but can be quite costly. These are essentially plastic materials derived from acrylic polymers, commonly used as household glues. The effect of these is to bond the soil particles together, forming a compacted and bonded water resistant material. Various suppliers of these products are operating in South Africa, each with specific formulations to develop their own products. As for petroleum resins, the bonding or gluing action of these products is used to improve the strength of the treated materials.
- **Other products** cover a wide range of materials primarily based on cement, bitumen emulsion or other standard components, such as lime or granulated blast furnace slag. The mechanism of action of these products depends on their primary component. Cement-based products hydrate and bond the particles together, as is the case with normal cement stabilization. Many of the cement-based products, however, have special additives or other components, e.g., polypropylene fibres, to make the treated material more flexible. A similar situation applies to the bitumen based products, where additional chemicals, e.g., urea formaldehyde, are added to enhance the bonding and or strengthening properties of the product. These products rely on a gluing action for their performance.

The use of non-traditional soil stabilizers should be considered when:

- Cost comparisons show them to be **economically viable** compared to traditional stabilizing agents, such as lime or cement.
- Testing shows that the non-traditional stabilizers are **effective in achieving the desired properties** of the material to be stabilized. Chapter 3: 6 covers this aspect in more detail.
- The **product is accredited** by a body, such as Agrément.

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TRH Revisions

Many of the TRH guideline documents are in the process of being updated. See the SANRAL website, www.nra.co.za for the latest versions.

APPENDIX A: SUMMARY OF TRH14 CLASSIFICATION SYSTEM FOR GRANULAR MATERIALS, GRAVELS AND SOILS

Table A.1 Summary of TRH14 Classification System for Granular Materials, Gravels and Soils

<table>
<tr><th>Groups</th><th colspan="3">G1, G2, G3: Graded Crushed Stone</th><th colspan="3">G4, G5, G6: Natural Gravels</th><th colspan="4">G7, G8, G9, G10: Gravel Soil</th></tr>
<tr><td>Description</td><td>G1 Crushed unweathered rock</td><td colspan="2">G2, G3 Crushed rock, boulders or coarse gravel</td><td colspan="3">Natural gravel; may be mixed with crushed rock such as boulders. May be cementitiously or mechanically modified.</td><td colspan="4">Categorised in terms of properties below.</td></tr>
<tr><td>Material Class</td><td>G1</td><td>G2</td><td>G3</td><td>G4</td><td>G5</td><td>G6</td><td>G7</td><td>G8</td><td>G9</td><td>G10</td></tr>
<tr><td colspan="11">GRADING</td></tr>
<tr><td>Sieve Size (mm)</td><td>Nominal max size 37.5 mm[1]</td><td colspan="2">Nominal max size 28 mm[1]</td><td></td><td colspan="2" rowspan="10">Max size 64 mm or two-thirds of compacted layer thickness, whichever is smaller.</td><td rowspan="10">Max size, in place, after compaction, shall not be greater than two-thirds of the layer thickness.</td><td colspan="3" rowspan="10">No grading requirements</td></tr>
<tr><td>50</td><td>100</td><td colspan="2"></td><td>100</td></tr>
<tr><td>37.5</td><td>100</td><td colspan="2"></td><td>85 – 100</td></tr>
<tr><td>28</td><td>84 – 94</td><td colspan="2">100</td><td>–</td></tr>
<tr><td>20</td><td>71 – 84</td><td colspan="2">85 – 95</td><td>60 – 90</td></tr>
<tr><td>14</td><td>59 – 75</td><td colspan="2">71 – 84</td><td>–</td></tr>
<tr><td>5</td><td>36 – 53</td><td colspan="2">42 – 60</td><td>30 – 65</td></tr>
<tr><td>2</td><td>23 – 40</td><td colspan="2">27 – 45</td><td>20 – 50</td></tr>
<tr><td>0.425</td><td>11 – 24</td><td colspan="2">13 – 27</td><td>10 – 30</td></tr>
<tr><td>0.075</td><td>4 – 12</td><td colspan="2">5 – 12</td><td>5 – 15</td></tr>
<tr><td>Grading Modulus (min)</td><td colspan="3">n/a</td><td>n/a</td><td>1.5</td><td>1.2</td><td colspan="4">n/a</td></tr>
<tr><td>Flakiness Index</td><td colspan="2">Max 35% on weighted average of -28 and -20 mm fractions</td><td>n/a</td><td colspan="3">n/a</td><td colspan="4">n/a</td></tr>
<tr><td>Crushing Strength</td><td colspan="2">10% FACT (min) 110 kN <u>or</u> ACV (max) 29%</td><td>n/a</td><td colspan="3">n/a</td><td colspan="4">n/a</td></tr>
<tr><td colspan="11">ATTERBERG LIMITS</td></tr>
<tr><td>Liquid Limit (max)</td><td>25</td><td colspan="2">25</td><td>25</td><td>30</td><td>n/a</td><td>n/a</td><td colspan="3" rowspan="4">No Atterberg Limit requirements</td></tr>
<tr><td>Plasticity Index, PI (max)</td><td>4</td><td colspan="2">6</td><td>6</td><td>10</td><td>12 or 3 GM^2 + 10</td><td>12 or 3 GM^2 + 10</td></tr>
<tr><td>Linear shrinkage, % (max)</td><td>4</td><td colspan="2">3</td><td>3</td><td>5</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Linear shrinkage x -0.425 mm sieve (max)[3]</td><td colspan="3">n/a</td><td>170</td><td>170</td><td>n/a</td><td>n/a</td></tr>
<tr><td colspan="11">BEARING STRENGTH AND SWELL</td></tr>
<tr><td>CBR, % (min) at MDD[4]</td><td>n/a</td><td colspan="2">80 at 98%</td><td>80 at 98%</td><td>45 at 95%[5]</td><td>25 at 93%</td><td>15 at 93%</td><td>10 at in situ</td><td>7 at in situ</td><td>3 at in situ</td></tr>
<tr><td>Swell, % (max) at MDD</td><td>n/a</td><td colspan="2">0.2 at 100%</td><td>0.2 at 100%</td><td>0.5 at 100%</td><td>1.0%</td><td colspan="4">1.5%</td></tr>
<tr><td colspan="11">FIELD COMPACTION</td></tr>
<tr><td>Base (upper and lower)</td><td>86 – 88% AD-CS</td><td>100 – 102% MDD</td><td>98% MDD</td><td>98% MDD</td><td></td><td></td><td colspan="4"></td></tr>
<tr><td>Subbase (upper and lower)</td><td>86 – 88% AD-CS</td><td>100 – 102% MDD</td><td>95% MDD</td><td>95% MDD</td><td></td><td></td><td colspan="4"></td></tr>
<tr><td>Selected layers</td><td></td><td colspan="2"></td><td></td><td colspan="6">93% MDD</td></tr>
<tr><td>Subgrade</td><td></td><td colspan="2"></td><td></td><td colspan="6">90% MDD</td></tr>
<tr><td>Material Class</td><td>G1</td><td>G2</td><td>G3</td><td>G4</td><td>G5</td><td>G6</td><td>G7</td><td>G8</td><td>G9</td><td>G10</td></tr>
</table>

<u>Notes:</u>

1. G1 adjustments to the grading can only be made using crusher dust or other fractions from the parent rock. Only in exceptional cases can a maximum 10% non-plastic fines be added. G2 and G3 materials may be a blend of crushed stone and other fine aggregate to adjust the grading.
2. GM is the grading modulus (see Chapter 3: 2.3.2)
3. Only applicable to nodular calcretes
4. MDD is the maximum dry density determined by the modified AASHTO method.
   In dry areas (Weinert N > 10) and AADT < 300 vpd CBR can be reduced to 25% @ 95% MDD if subbase cover is at least 150 mm.