

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 3

Materials Testing

THE SOUTH AFRICAN NATIONAL



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 3: Materials Testing

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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 978-1-920611-03-3

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CHAPTER CONTEXT

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 3.

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 in pavement structures, including soils and gravels, aggregates, bituminous materials and cementitious materials. The tests used for each material are briefly described, the complete test number given, with the applicable reference for the full test method. Where possible and applicable, interesting observations or experiences with the tests are mentioned. Appendix A gives test methods for cementitiously stabilized materials that are not provided in any other guideline or specification. Appendix B details the test methods for Agrément Certification. Appendix C contains a complete list of the migration of old test methods to the SANS 3001 series. Differences between the old and new methods are mentioned. Chapters 3 and 4 are complementary.

Chapter 4: Standards follows the same format as Chapter 3, but discusses the standards used for the various tests. This includes applicable limits (minimum and maximum values) for test results. Material classification systems are given, as are guidelines on mix and materials composition.

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 pre-coating fluids and tack coats, bituminous binders, bitumen stabilized materials, asphalt, spray seals and micro

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surfacing, 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 11: Documentation and Tendering covers the different forms of contracts typical for road pavement projects, including conventional contracts, product performance guarantee systems, design and construct, and concessions. In the documentation sections, the design, contract and tender documentation are discussed. The tender process is also discussed, from pre-qualification, through site inspection, to tendering and tender evaluation. The contract documentation is discussed, 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.

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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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1. INTRODUCTION

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

South African test protocols have been developed over many years by drawing on overseas information, and adapting this to local materials and conditions. Test protocols used by the road building industry are constantly evolving and being updated due to several factors, such as:

- Advances in pavement design, which demand more **sophisticated testing** to evaluate engineering properties more accurately.
- The introduction of **new design and construction technologies**.
- Advances in automated and computerised **testing equipment**.
- Introduction of **new materials** and construction techniques.

The authorities and publications relevant to the methods used in South Africa to test road building materials are given in Table 1. TMH1 is in the process of being revised into SANS 3001 standards, see the side box and Appendix C for details. Many of the older SABS and SANS tests are also migrating to SANS 3001 tests, as detailed in the Appendix.

There are a number of field tests that are used particularly on existing pavement structures, which are not included in the documents in Table 1, such as:

- **Functional pavement tests:** riding quality, rut depth measurements, skid resistance
- **Structural tests:** deflection, dynamic cone penetrometer (DCP), ground penetrating radar (GPR)



Migration to SANS 3001

TMH1, and some SANS and SABS test methods are in the process of being revised and translated into SANS 3001 Standards. The latest list of SANS 3001 Standards published to date is available on the Internet via SABS's WebStore (www.sabs.co.za, under Quick Search Criteria" enter "3001").

A complete list of the New SANS methods and the TMH1 methods which have been replaced are included in Appendix C.

It is recommended that wherever possible the new standards should take precedence over the old TMH1 methods. In the text, the SANS 3001 Standard Numbers are quoted. If the Standard has not yet been published then the old number is given, with the new SANS number that will be used when published in parenthesis. Please note that certain TMH1 methods deemed as no longer in use or appropriate have been omitted from the SANS 3001 series.

Some of these test methods are new SANS methods and some can be found in draft TMH6, Special Methods for Testing Roads. COTO is in the process of compiling guidelines for network level management of performance measurements, which will be published as TMH13. These include guidelines for:

- Roughness (COTO, 2007)
- Rutting (COTO, 2010)
- Skid resistance and texture (COTO, 2008)
- Pavement deflection (COTO, 2009)
- Imaging and GPS Technologies (COTO, 2010)

The testing of existing pavement structures is discussed further in Chapter 6.

The aim of this chapter is not to repeat the various test methods, but to provide an overview of the tests used for various road building materials, with recommendations for the selection of the most appropriate tests that should be undertaken in specific instances. It also covers precautions that should be taken with certain tests to avoid potential pitfalls with the test protocols, as well as with the interpretation of the results.



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.

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Table 1. Authority and Publications of Test Methods for South African Road Building Materials

Publication/Authority	Details
Technical Methods for Highways 1 (TMH1): Standard Methods of Testing Road Construction Materials (1986)	Tests on soils and gravels, asphalt, concrete, bituminous materials and cement .
SANS 3001 (SABS, current)	The TMH1 test methods are currently being revised and translated into South African National Standards . SABS website www.sabs.co.za , standards catalogue, quick search: 3001. A complete list of the old TMH1 and new SANS test method numbers is included in Appendix C.
SABS 1200 (SABS, current)	The test methods are based largely on ASTM and British Standards (BS) with some reference to AASHTO and International Petroleum (IP), now Energy Institute UK methods.
COLTO Standard Specifications for Road and Bridge Works for State Road Authorities (1998) <i>Note that these specifications are currently being revised, see sidebar on the next page. Referred to as Standard Specifications in this chapter.</i>	Testing of aggregates, concrete, soils, gravel, crushed stone, bitumen, asphalt, structural tests, silicone sealants and water for construction .
TG1 Technical Guideline: The Use of Modified Bituminous Binders in Road Construction, second edition November 2007	Test methods for modified bituminous binders . Asphalt Academy website www.asphaltacademy.co.za
TG2 Technical Guideline: Bitumen Stabilised Materials – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials, second edition, May 2009	Test methods for bitumen stabilized materials (BSMs). Published by the Asphalt Academy.
ASTM International, originally known as American Society for Testing & Materials	ASTM test methods are currently used in the testing of bituminous binders . These test methods can be ordered from www.astm.org .
AASHTO: American Association of State Highway Officials	AASHTO test methods are used in the testing of bituminous binders . The test methods can be ordered from the AASHTO Bookstore https://bookstore.transportation.org

1.1 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, the decrease in material quality should be in approximately uniform steps. 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.

1.2 Changes in Sieve Sizes

Until recently, the testing of soils and gravels, aggregates, asphalt, bituminous materials, concrete and cement has been carried out in accordance with the test methods given in TMH1, Standard Methods for Testing Road Construction Materials (1986). The translation of these test methods into SANS 3001 standards is well underway.

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

- Simplify
- Avoid radical changes, except where necessary
- Follow worldwide trends in moving to simple metric units



COLTO vs TRHs

Some of the testing requirements for materials in the "G" category differ between those in the TRH4 and TRH14 and those specified in COLTO's **Standard Specifications for Road and Bridge Works for State Road Authorities** (1998). Testing should be carried out in compliance with the requirements specified for a particular project.

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- Use ISO 3310 (ISO, 1999 & 2000) 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 2.

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. In this SAPEM manual, only the new sieve sizes are used.

Table 2. Changes in Sieve Sizes from THM1 to SANS

Sieve Size (mm)	
TMH 1	SANS
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

2. TESTS ON 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 that occurs due to stresses arising from expansion or contraction with temperature changes.
- **Weathering and decomposition** due to 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 in 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 will have a considerable variation in the degree of weathering and in their distribution of particle sizes or gradation. These variations largely determine the quality of the soil in terms of its suitability for use as a road building material.



Soils and Gravels

Gravels: Naturally occurring materials which are predominantly coarser aggregate particles, and have considerable strength due to aggregate interlock. Finer material occurs with aggregate particles.

Soils: Large proportion of fine materials.

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**”.

Standards applicable to soils and gravels are covered in Chapter 4: 2. The following sections cover the applicability and peculiarities of the various tests that are carried out on soils and gravels.

2.2 Material Classification Systems

Several different materials classification systems have been developed over the years. These are discussed in Chapter 4: 2.3. In South Africa, the TRH14 system is most commonly used. In this 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 Chapter 4.

The tests required for soils and gravels vary according to their classifications in terms of TRH14. These tests are listed in Table 3. Some additional tests for properties specified in the Standard Specifications are also included. The type and rigour of testing depends on the location of the materials in the pavement and the risks associated with incorrect assumptions of material properties. The tests themselves are all discussed in later sections of this Chapter.



TRH vs COLTO Material Requirements

Some of the requirements for materials in the “G” category differ between those in the TRH4 (1996) and TRH14 (1985) and those specified in COLTO (1998). It should be noted that the TRH’s are only recommendations while the COLTO document is the official specification.

There are also differences between the COLTO specification and those specified in the SANS 1200 series, such as in SANS 1200 D: 1988 (Earthworks), and SANS 1200 M: 1996 (Roads General). **Standards from the relevant documents should be applied, depending upon which specification is used for a particular project.**

Table 3. Typical Tests Carried out on Soils and Gravels

Tests Required	Material Classification TRH14							Test Method ¹	Comments	Chapter Reference
	G4	G5	G6	G7	G8	G9	G10			
Grading (sieve analysis)	✓	✓	✓	✓	✓	✓		SANS 3001-GR1 SANS 3001-GR2	Std Specs ² specify GM ³ on G7 to G9 quality materials	Section 2.3
								SANS 3001-GR3	Hydrometer analysis	Section 2.3
Moisture Content	✓	✓	✓	✓	✓	✓	✓	SANS3001-GR20	Used as part of many other tests	Section 2.4
Atterberg Limits	✓	✓	✓	✓	✓	✓		SANS 3001-GR10 SANS 3001-GR12	TRH14 and Std Specs requirement	Section 2.5
Strength (CBR)	✓	✓	✓	✓	✓	✓	✓	SANS 3001-GR40	TRH14 and Std Specs requirement	Section 2.8
Swell (CBR)	✓	✓	✓	✓	✓	✓	✓			
Flakiness Index	✓							SANS 3001-AG4	Std Specs requirement	Section 3.2.2
Durability										
Soundness of Mudrocks and Shales (Venter Test)	✓	✓	✓	✓	✓	✓		SANS 3001-AG13	Std Specs requirement for mudrock include Venter Test and 10% FACT	Section 2.9
10% FACT (wet)	✓	✓	✓	✓	✓	✓		SANS 3001-AG10		
Durability Mill Index	✓							SANS 3001-AG16	Std Specs requirement	
Soluble Salts										
pH & Electrical conductivity	✓	✓	✓	✓	✓	✓		TMH1 A20 & A21T (SANS 3001-GR32)	TRH14 and Std Specs requirement	Section 2.10
In Situ Compaction										
Nuclear Gauge	✓	✓	✓	✓	✓	✓		SANS 3001-NG5	Considered the reference test for measuring density	2.7.1
Sand Replacement								TMH1 A10(a) (SANS 3001-GR35)	Only used in for some applications	2.7.2

Note

1. SANS test method in brackets will be the new SANS 3001 number when published.
2. Standard Specifications
3. Grading Modulus

2.3 Grading Tests

The grading of a material gives an indication of important attributes of a material such as:

- **Maximum particle size**
- **Relative distribution of particle sizes**, i.e., are there gaps or too much or too little of a particular fraction?
- **Amount of fine material present**, which can affect compactibility and permeability.

Grading envelopes are typically based on the Fuller maximum density gradings. For maximum density, a perfect grading would usually be calculated using Equation (1):

$$P = (d/D)^{0.5} \quad (1)$$

where P = % passing a sieve with aperture d
D = maximum particle size



Variability in Gradings

Allowance needs to be made for the variability in materials, and thus gradings should be evaluated in conjunction with other critical properties such as density and strength.

To obtain a grading envelope for a specific maximum size, this model is usually calculated using different exponents, typically 0.25 or 0.3 and 0.45. This gives a lower and an upper bound of achievable densities.

Allowance needs to be made for variability in gradings and material should not be rejected on grading alone, but in conjunction with not satisfying other critical properties such as density and strength. Grading is one of the most important properties of road building materials as coarse grained materials can normally carry much heavier loads without deformation than finer materials. When evaluating materials, use engineering discretion to employ a holistic view of all properties and not just grading alone.

It should be remembered that the grading analysis is based on the mass of particles on each sieve, which assumes that the density of the particles is relatively constant. If there are differences in the densities, the grading curve may not be smooth and apparent gaps may occur. This is common, for instance in beach sands with significant quantities of high density minerals, e.g., zircon, ilmenite, and rutile, which tend to be single-sized, accumulate on one sieve and boost the mass of material on that sieve, although the volume is relatively low.

Gradings are typically shown as a grading curve, and are usually specified as an envelope to accommodate the typical natural variation that occurs, even in crushed gravels. A typical grading curve for a natural gravel, with the TRH14 grading envelope for G4 materials, is shown in Figure 1, with the TMH1 and SANS sieve sizes.

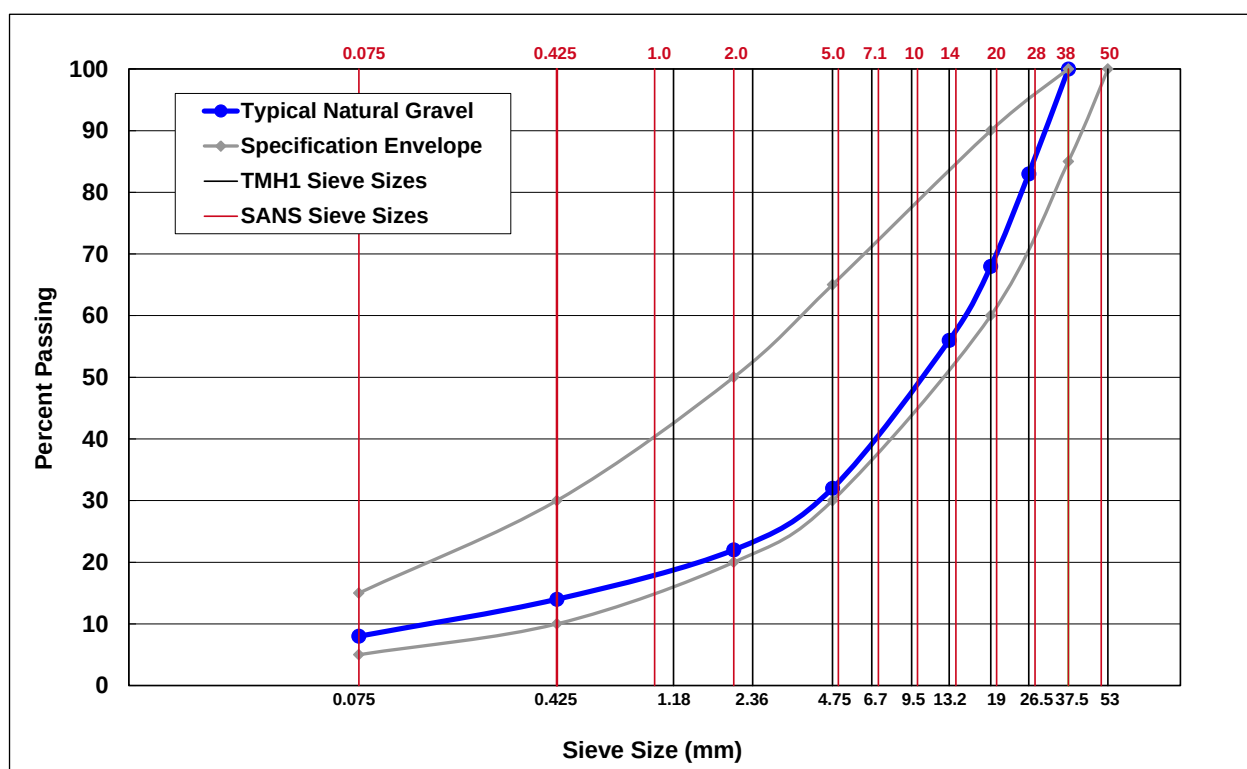


Figure 1. Typical Grading of a Natural Gravel

Three different test protocols can be used to obtain the grading of soils and gravels: wet preparation, dry preparation and the hydrometer method. SANS 3001-PR10 gives a procedure for checking, handling and maintenance of sieves.

(i) Wet Preparation Sieve Analysis Method (SANS 3001-GR1)

In this reference method, water is used to wash the sample through a set of sieves. The particles retained are washed clean on each of the sieves with successively smaller openings, ensuring accurate grading results down to the fraction passing the 0.075 mm sieve. Material passing the 0.425 mm sieve, known as the "soil fines", is used in the determination of Atterberg Limits. A typical sieve and nest of sieves used in a grading test are illustrated in Figure 2.



Report the Test Method

When test results are reported, the test method used must be stated.



Figure 2. Sieves for Grading Determination

For base materials with potential plasticity problems, the fines passing the 0.075 mm sieve are also tested for Atterberg Limits and the results can give a clear indication of the potential moisture sensitivity of the material.

(ii) Dry Preparation Sieve Analysis Method (SANS 3001-GR2)

This is a much quicker method as the grading is carried out by sieving the dry material through the nest of sieves down to 0.425 mm, without washing. This makes it less accurate than the wet preparation method, but it is suitable for use as a process control test especially for crushing of base and aggregates.

When using the dry preparation method the fines passing the 0.425 mm sieve should not be used for the determination of Atterberg Limits, as they may not contain all of the clayey constituents compared with the fines produced using the wet preparation method. The method is best suited to low plasticity materials with few fines.

(iii) Hydrometer Method (SANS 3001-GR3)

This method utilises a hydrometer, shown in Figure 3, to determine the distribution of the grain sizes in the material. It is useful in determining grain sizes of less than 0.075 mm so that the proportion of silts and clays can be assessed. This information can be used, together with the material's Atterberg Limits, to evaluate its "potential expansiveness" (van der Merwe, 1964).



Dispersants in Hydrometer Tests

Dispersants are added to the water during hydrometer testing to deflocculate the fine (clay) materials. Over the years various types have been used, with a 50:50 sodium silicate and sodium oxalate solution being used in TMH1. ASTM, BS and SANS 3001-GR3 use sodium hexametaphosphate (in different proportions to the total solution). The standard South African method between 1948 and 1970 used the sodium silicate-oxalate mixture and between 1970 and 1979, the hexametaphosphate solution was used. The 1979 TMH1 revision reverted to the sodium silicate-oxalate mixture. Recent investigations have, however, shown that there can be significant differences, depending on the dispersant used. Care should thus be exercised when interpreting results from different laboratories, where the methods may vary.



Figure 3. Hydrometer

2.3.2 Grading Modulus

The Grading Modulus provides a simple but useful method for assessing the properties of soils and gravels. It is calculated using either Equation (2), which uses the percentage retained on the sieves, or Equation (3), which uses the percentage passing the sieves.

$$GM = \frac{R_{2.00\text{mm}} + R_{0.425\text{mm}} + R_{0.075\text{mm}}}{100} \quad (2)$$

$$GM = \frac{300 - (P_{2.00\text{mm}} + P_{0.425\text{mm}} + P_{0.075\text{mm}})}{100} \quad (3)$$

where $R_{2.00\text{ mm}}$ etc. = percentage *retained* on the indicated sieve size
where $P_{2.00\text{ mm}}$ etc. = percentage *passing* the indicated sieve size

Material with a high Grading Modulus (> 2.0) indicates that it is coarsely graded and of relatively good quality, while material with a low Grading Modulus is indicative of material with finer grain sizes, and poorer road building quality.

2.3.3 Fineness Modulus

The fineness modulus of sand is used as a parameter in the proportioning of concrete mixes at design stage. It is an empirical factor obtained by adding the total percentages of a sample of the aggregate retained on each of a specified series of sieves, and dividing the sum by 100. The sieve sizes used are 0.15 mm, 0.3 mm, 0.6 mm, 1 mm, 2 mm and 5 mm.



Grading Modulus

Materials with a high GM (> 2) are typically coarse graded, good quality materials. A low GM indicates finer grained materials of poorer quality.

2.4 Moisture Content Tests

The moisture content of a material is determined using SANS 3001-GR20 "Determination of the moisture content by oven-drying". This test is also known as the gravimetric moisture content.

The test consists of determining the mass of a sample in a tared container before drying. The container with the sample is placed in a forced draft type oven that is set between 105 and 110 °C and is dried to constant mass (usually overnight). The mass of the container with the sample is determined again. The moisture content is calculated using the difference in the mass of the moist and dried material, expressed as a percentage of the mass of the dry material.

2.5 Atterberg Limit Tests

Atterberg Limit tests measure the plasticity of a soil. The limits are described in terms of the moisture content measured at the boundaries between the solid, plastic and liquid states of the soil fines ($< 0.425\text{ mm}$). The Plasticity Index (PI) is a measure of the moisture content range of the plastic state and is calculated as illustrated in Figure 4 and using Equation (4).

In the linear shrinkage test, a trough filled with material at its liquid limit is oven dried. The linear shrinkage is the percentage reduction in length of the bar of material in the trough after drying.

The liquid limit is determined using the equipment in Figure 5. Material is mixed with water in the bowl, and then a groove is carved through the mixed material (as shown on the right). The handle is turned and the bowl dropped from a specific height. The number of blows until the material portions flow together across about 10 mm is measured, and is associated with the moisture content. The test methods specify the number of blows and the detailed calculation to determine the liquid limit.

The plastic limit is determined by taking mixed material, and rolling about 3 g into a continuous thread. The moisture content at which the thread crumbles at about a 3 mm diameter is the plastic limit.

The plasticity index (PI) and to a lesser extent linear shrinkage (LS), gives a strong indication of the sensitivity of the material to water. As a guide, the LS should be about half of the PI, but depending on the clay mineralogy, this does not always apply. With experience, the PI can provide a clear indicator of the performance of a material. Materials with low PI values can be expected to perform better than materials with high PI values.

$$PI = LL - PL \quad (4)$$

where PI = Plasticity Index
LL = Liquid limit
PL = Plastic limit

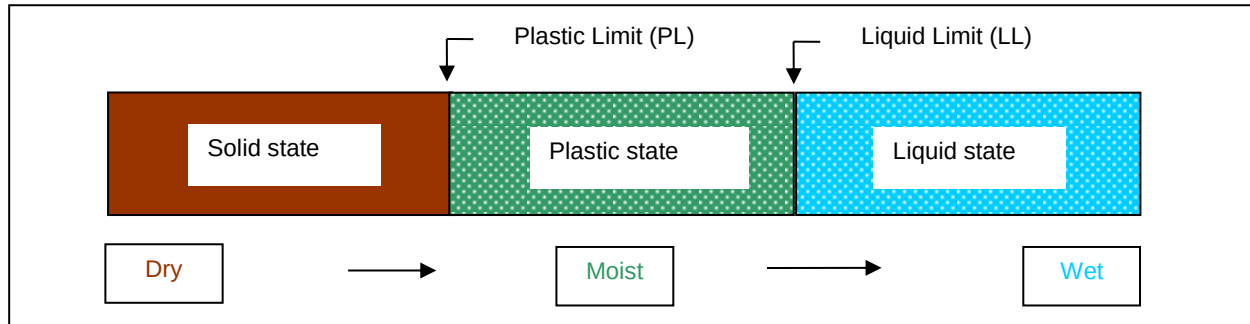


Figure 4. Atterberg Limits



Figure 5. Apparatus and Testing of Atterberg Limits

When the linear shrinkage of a material is found to be less than 0.5%, the material is considered as “non-plastic” (NP). Materials with linear shrinkage values between 0.5% and 1.5% are described as “slightly plastic” (SP).

To determine the Atterberg limits, three methods are available:

- **Flow curve** method (SANS 3001-GR12): This should be used as a reference method, particularly for materials with high plasticity.
- **Two-point** method (SANS 3001-GR11): This method is recommended for routine and duplicate testing.
- **One-point** method (SANS 3001-GR10): This method is for experienced testers.



Indicator Tests

Grading by sieving and Atterberg limits are often referred to as **Indicator Tests**. They provide very useful basic information on grading and moisture sensitivity, which critically influence the performance of a material.

2.6 Compaction and Density Tests

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 reduced.



Density Measurements

Both the field density and MDD tests have moderate to poor repeatability and thus do not give exact answers. Be sure to carry out the tests strictly according to the test procedures to get the most accurate results.

Over the years, the reference densities used to determine the level of compaction of soils and gravels have evolved. Ralph Proctor introduced what became known as the Proctor Test in 1933, where material was compacted in three layers in a standard 100 mm diameter steel mould using a standard hammer. The highest density achieved after varying the material's moisture content is calculated as a dry density and is known as the "maximum dry density" of the particular material. The moisture content required to achieve this density at the specified Proctor compaction effort is known as the material's "optimum moisture content".

This test is still used in dam earthworks construction but has been superseded in the road building industry by a similar type of test. Now, a much higher compactive effort is applied to the material in five layers in a larger, 150 mm diameter mould. Maximum dry density and optimum moisture content values are determined in the same way. This was commonly known as the "Mod" or Modified AASHTO density. The correct term is now the maximum dry density or "MDD", and the test is generally used to control the field compaction of soils and gravels.

The **Maximum Dry Density (MDD)** and **Optimum Moisture Content (OMC)** test (SANS 3001-GR30) serves two distinct purposes:

- The **OMC** is the moisture content at which specimens for other tests, such as CBR, Unconfined Compressive Strength and Indirect Tensile Strength tests are compacted, as well as being an indicator of the best moisture content for compacting materials in the field.
- The **MDD** provides a means of comparing field compaction with a standard level of compaction (percent of MDD). MDD gives an indication of the maximum density when compacted at OMC using a standard compactive effort. The equipment used to prepare the specimens is shown in Figure 6.



Reporting of MDD Results

Because of variations in grading (even in a split sample) and other properties, single MDD values should be treated with caution. Some authorities require a MDD for every field density point while others call for a sequential mean of, say, the last four results.

To carry out this test, for all the applications, the field sample is prepared by scalping on the 37.5 mm sieve and discarding the coarser material.



Figure 6. Soil Compaction Equipment (with protective coverings removed for illustration)

MDD and CBR testing of cohesionless sand are problematic. Several methods are used to obtain maximum compaction, such as saturation compaction combined with vibration, or by using SANS 3001-GR30 with a thin rubber disc placed on top of each layer in the mould to reduce the bounce of the unconfined sand particles during compaction. The results, however, should be treated with caution and sound engineering judgement should be applied in their evaluation.



Cohesionless Sands

MDD and CBR testing of cohesionless sand is problematic.

2.7 In Situ Compaction Tests

Two different methods are routinely used for testing the compaction of soils and gravels: the nuclear method and the sand replacement method.

2.7.1 Nuclear Method

Nuclear gauges were introduced during the early 1980's to measure density and moisture contents on construction sites. There are currently two gauge types available:

- **Nuclear surface moisture-density gauge** that measures the density and/or moisture content of soils. This gauge is shown in Figure 7.
- **Nuclear thin layer density gauge**, which measures the density of asphalt layers.

The essential components of a nuclear gauge comprise:

- **Source of gamma radiation** for density measurement
- **Source of neutron radiation** for moisture content measurement
- **Detectors** of gamma radiation and slow neutron radiation as appropriate
- **Electronics** to convert the detected radiation into measures of density/moisture content

2.7.1.1 Mode of Operation

Nuclear density gauges do not provide a direct reading of the density of a material. The gauge emits gamma radiation from a Cesium source which passes through the material and is measured by detectors located in the base of the gauge, and converted by a microprocessor into a wet density reading. Moisture readings are obtained by counting slowed neutrons emitted by a neutron radiation source in the gauge and measured by a detector in the base of the gauge. Moisture readings are generally far less accurate than the wet density readings.

The gauge provides a measure of the average density of the material between the detector and the source.

The mode of operation involves either the backscatter method or the direct transmission method. The moisture content is determined by the backscatter method only, while the density is determined using either the backscatter or direct transmission method.

(i) Backscatter

The backscatter method commonly utilises one or two measurement positions. It involves placing the source and the detector on the surface. The gamma radiation emitted from the source is scattered back towards the detector, as illustrated in Figure 7(a). This method is performed rapidly and is truly non-destructive. However, the measurement depth is restricted to around 50 mm and measurements are biased toward the surface of the material. The method does, therefore, not provide a true measure of the average density of the layer.

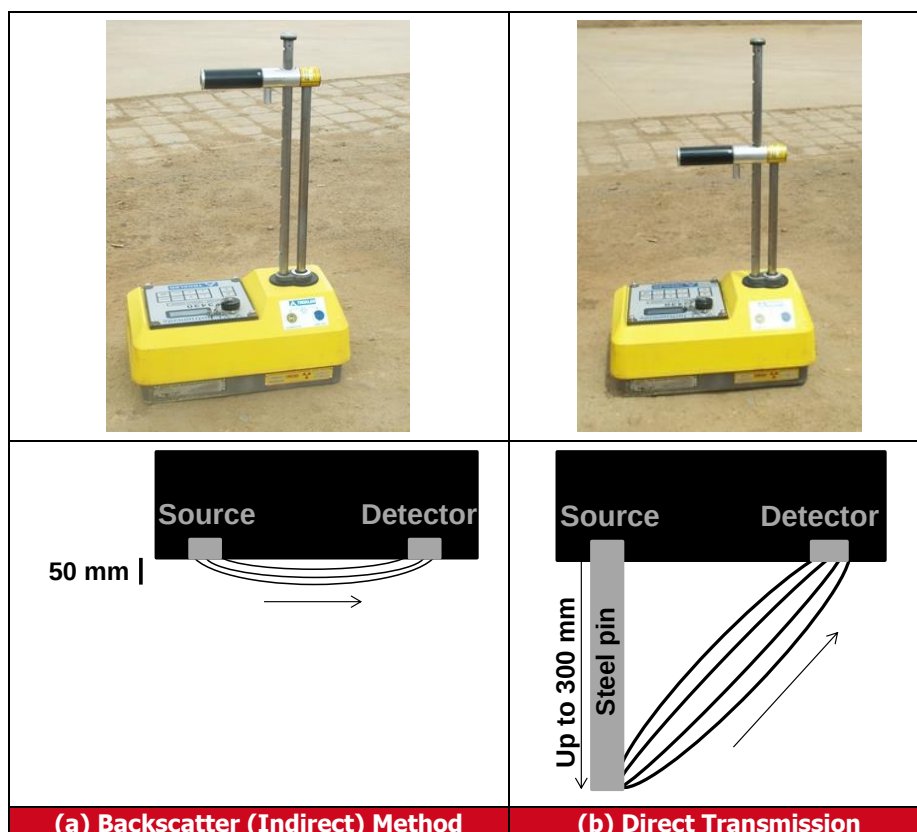


Figure 7. Nuclear Measurements

The backscatter method is very sensitive to surface roughness and is less precise than the direct transmission method.

(ii) Direct Transmission

The direct transmission method involves placing the source and detector on opposite sides of the material to be measured, i.e., the detector on the surface and the source within the material. During the direct transmission method, a small hole is pre-drilled in the test material and the nuclear gauge is placed on the surface over the hole. Using the source rod, the radioactive source is lowered in increments of 25 or 50 mm into the hole to a depth of up to approximately 200 mm to 300 mm. The gamma radiation emitted from the source then passes through the material to be measured before it is detected, as illustrated in Figure 7(b). This method is partially destructive in that it requires a hole approximately 25 mm in diameter in the material to contain the source. This hole is usually drilled.



Using Nuclear Devices

Nuclear devices are classified as hazardous materials and their use and storage must be carefully controlled by registered personnel only.

2.7.1.2 Test Methods

There are 5 SANS 3001 nuclear gauge tests, as shown in Table 4. The test method, SANS 3001-NG5, is the reference method and employs a nuclear instrument to measure moisture and density. Nuclear gauges, require calibration and regular validation using standard blocks linked to a reference set of three blocks held by the CSIR. Because the gauges are classed as Group VI Hazardous Materials their handling, maintenance, storage and disposal needs to be carefully controlled by competent (and registered) personnel, as described in SANS 3001-NG1.

Testing on standard calibration blocks has shown that without moving the gauge, for a set of 10 by 1 minute counts the resulting densities can vary over a range of up to 0.5% of the block density. Further, by switching the gauge off between sets of 10 by 1 minute counts, the average for each of the sets can vary over a range of up to 0.4% of the block density. It is thus clear that no single gauge reading can give an exact value of density.

Table 4. SANS 3001 Nuclear Gauge Tests

Test Number	Test Name
NG1	Administration, Handling and Maintenance of a Nuclear Gauge
NG2	Validation of Standard Calibration Blocks
NG3	Calibration of a Nuclear Gauge
NG4	Verification of a Nuclear Gauge
NG5	Determination of In Situ Density Using a Nuclear Density Gauge

When more than one gauge is to be used for density determination on a section of work, the following procedure is recommended:

- Establish that all the gauges have been **calibrated** (SANS 3001-NG3) using a set of standard blocks verified against the CSIR reference set of blocks (SANS 3001-NG2).
- The gauges have been **verified** (within the last 12 months) subsequent to calibration (see SANS 3001-NG4).
- **Average the readings** of all gauges used per section to determine the field density.

The presence of ferruginous, calcareous and organic materials in the layers can lead to problems with the interpretation of field density. In these situations it is recommended that trial sections should be constructed to determine a satisfactory level of compaction by observing and approving the compaction method, and taking field densities using both nuclear gauges and the sand replacement method. Based on the results, an acceptable level should be established and agreed to either using the test results or a set construction compaction method (i.e., a method specification).



Nuclear Moisture Measurements

Moisture measurements taken by a nuclear gauge are inaccurate, because the gauge measures any hydrogen in the soil, and not just hydrogen in the moistures. Samples of the moist soil must, therefore, always be taken to determine the moisture content gravimetrically in the laboratory. This is to determine the true dry density and to provide a rough calibration for the particular nuclear measurements.



Moisture Contents for Density Measurements

It is advisable to determine the moisture content at each point by the gravimetric method (SANS 3001-GR20) when calculating the dry density of the layer at the test point.

The accuracy of the moisture contents measured by the nuclear gauge tends to be variable, depending upon chemical constituents in the layer, and the presence of hydrocarbons such as those found in bituminous treated materials and materials containing fragments of asphalt. There is hence the need to make a correction to the instrument moisture contents by taking a physical sample from the full depth of the layer and determining its oven dried moisture content in the laboratory (gravimetric method, SANS 3001-GR20). The moisture correction should be based on the average of at least six test points obtained from the first trial section. Once the moisture correction is reliably known it is applied to the instrument, as long as the material remains uniform. However, it should be frequently checked on subsequent construction sections or test areas.

2.7.2 Sand Replacement Method

This is not the reference method for determining the density of a layer. It may, however, be used in certain instances where the material contains substances that may affect the measurements done by the nuclear method. This method may also be considered when determining the density of pavement layers in a test pit, when the close proximity of the sides of the test pit could affect the nuclear measurements.

The results obtained from sand replacement tests are subject to even greater variations than the nuclear gauge and are especially sensitive to operator error. While results in fine-grained cohesive materials may be fairly similar, results in crushed stone bases may be elevated by up to 4%. This test method is covered in TMH1 A10(a), but will be republished as SANS 3001-GR35.

2.8 Strength Test: California Bearing Ratio (CBR)

For gravels and soils of G4 and lesser quality the CBR test (SANS 3001-GR40) is carried out on compacted specimens of the material. The material, as in the case of the MDD/OMC test, is scalped on the 37.5 mm sieve and the oversize is discarded.

The CBR of a material is an indirect measure of shear strength or bearing capacity under a single load. The testing equipment is shown in Figure 8. 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 variations. 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. Reported CBR values are always soaked values; unsoaked CBR results are almost meaningless unless accompanied by an indication of the density and moisture content at which they were determined.



Scalping on the 19 mm Sieve

The preparation method in SANS 3001-GR40 differs from that in the TMH1 Method A7 where the material was sieved through the 19 mm sieve, with any material retained on this sieve being lightly crushed to pass it. The test specimen for the SANS 3001-GR40 method is simply scalped at 37.5 mm, and the oversize discarded.



Figure 8. CBR Testing Equipment

Because of the variation in quality of most natural gravels the link between the 'G' designation and range of CBR values is quite broad, as shown in Table 5. CBR values tend to increase with increased compaction and thus a marginally substandard CBR could be improved by calling for a higher than normal compaction. Particularly in areas where there is a shortage of suitable material, the use of intermediate categories should be considered.

Table 5. Minimum CBR per Material Class

Material Class	Compaction	CBR
G4	98% of MDD ¹	> 80%
G5	95% of MDD	> 45%
G6	95% of MDD	> 25%

Note

1. MDD = maximum dry density

2.9 Durability Tests

Various durability tests, as shown in Table 3, are carried out on **soils and gravels**, as briefly described below.

- **Soundness of Mudrocks (SANS 3001-AG13, Venter Test).** This is a Standard Specification requirement for determining the soundness of fine-grained mudrock, which includes shales (fissile rock) and mudstones (massive rock). The primary objective is to determine the degree and type of disintegration/slaking that will occur. The test is carried out by soaking particles in water, and then oven drying them for five cycles, classifying the sample condition after each cycle into one of five classes. At the end of the test, the pattern of disintegration is evaluated and the sample is given an overall classification rating.
- **10% FACT (SANS-AG10).** This is also a Standard Specification requirement to determine the durability of mudrock and shale. The procedure is described in SANS 3001-AG10, where the load required to produce 10% of fines is determined on dry and then wet particles. In the wet test, the particles are soaked in water for 24 hours before the loading is carried out. The wet/dry relationship is used to assess the durability of various rocks.
- **Durability Mill Index, DMI (SANS AG16).** This test is a Standard Specification requirement for G4 quality materials. Three specimens of material of a specified grading are tumbled in a rotating drum for a set number of rotations under three conditions: wet with steel balls, dry with steel balls and wet without steel balls. After the required number of rotations is complete, the grading and PI are determined on each. The extent to which the material has disintegrated is used to calculate the Durability Mill Index. This is obtained by taking the highest fraction passing the 0.425 mm sieve and multiplying it by the highest PI value obtained from any of the four conditions (including the material before treatment, which should seldom be the highest). The test has also been used as an indicator of problems for G1 or G2 crushed stone dolerite bases.



Figure 9. Durability Mill Apparatus

2.10 Testing of Deleterious Materials

Testing of deleterious materials is done by determining the soluble salts, pH, cation exchange capacity and X-ray diffraction.

2.10.1 Soluble Salts

The level of soluble salts in soils and gravels is determined by means of electrical conductivity testing using a conductivity meter. The test is carried out on the 7.1 mm sieve, which is saturated to form a paste. This test is done in accordance with TMH1 Method A21T.

The pH of a soil or gravel is determined using a pH meter on a suspension prepared by mixing the fraction passing the 0.425 mm sieve with water. The test is carried out in accordance with TMH1 Method A20.

These tests are affected by the condition of the test apparatus and are currently being revised to provide more consistent and reliable results. They should be published in 2015 as a single test SANS 3001-GR32.

2.10.2 Cation Exchange Capacity (CEC) and X-Ray Diffraction (XRD) Testing

In the engineering context, clay is defined as any particle smaller than 0.005 or 0.002 mm, depending on the classification system used. It is important to differentiate between clay-sized particles (finer than the above limits) and clay minerals. Clay minerals are layered alumina-silicate minerals with unique properties that coincidentally, are also finer than 0.002 mm. Clay minerals typically show plasticity, are often volumetrically unstable, but importantly, have surface charges that allow the adsorption of different cations. The type of cation affects the properties of the

clay, with sodium cations for instance causing much higher plasticities than calcium (hence the reduction in plasticity caused by lime stabilization). It is also the sodium ions attached to clays for instance that cause soils to be dispersive.

The cation exchange capacity test is usually carried out in pedological (agricultural) laboratories to determine the quantity and type of cations held by the clays. The test essentially displaces the cations using various compounds (eg, ammonia) and the displaced cations are then identified and quantified.

X-ray diffraction is used to identify minerals in rocks and soils. This requires sophisticated and expensive equipment and is carried out by specialist material laboratories. Small samples of the soil or rock are ground to a fine powder which are then placed in the XRD equipment and scanned, producing a series of peaks that are unique to individual minerals. However, a number of the clay mineral peaks coincide with each other and it is usually necessary to carry out various pre-treatments of the ground material in order to differentiate between the different clays. Smectites usually require glycol solvation but could also require heat treatments if chlorite and kaolinite are present.

XRD is the only economic and effective way of identifying the type of clay in soils and rocks and is particularly important for the identification of smectite (montmorillonite) clays that cause so many problems with expansiveness of soils and durability of (mainly) basic crystalline materials. A quantitative assessment of the clays is usually provided but this can significantly overestimate the amount of smectite in soils and should be used with caution.

3. TESTS ON 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, waste (dump) rock from mine waste dumps or ashes from certain combustion facilities. See Chapter 8: 3.5.7 and 4.5 for more mine waste and slags.

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

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

Tests are specifically designed to provide information on the properties of aggregates that are relevant to their position in the road pavement. A number of the tests used for aggregates are the same as for gravels and soils (covered in Section 2) and the details and interpretation of test results given in that section apply. The tests for aggregates used in asphalt, surfacing seals and for rolled-in chips, as well as in bitumen stabilized materials (BSMs) are covered in Section 1, while tests for aggregates used in concrete are included in Section 5.1.1.

Standards for aggregates are covered in Chapter 4: 3.

3.2 Tests on Aggregates Used in Subbase and Base Layers

Bearing in mind the definition of “aggregate” as a crushed product, aggregates used in the subbase and base layers fall, in accordance with TRH14, into G1, G2 or G3 classifications.

In general, these materials are not used in subbase layers; materials of lesser quality are usually used as subbase, with the higher quality crushed materials being reserved for use in the base layer. There are however, instances where the quality of natural gravels have to be boosted to meet requirements for subbase and in these cases crushed stone of G1, G2 or G3 quality is blended in with the natural gravel. In some cases, a natural gravel of G6 quality is blended with crushed stone aggregate to improve it to G5 quality, after which it can be stabilized to a subbase of C3 quality.

An array of tests is normally carried out on G1, G2 and G3 materials, with the aim of evaluating all of the properties of the aggregate that affect the performance of the material in the base layer. Reference is made to the Standard Specifications requirements for crushed stone base, as well as those in TRH14, which cover the testing requirements for these materials in detail. A summary of these tests is given in Table 6, and notes on their use are given below.

3.2.1 Grading: Sieve Analysis Testing (SANS 3001-GR1)

The sample of aggregate is sieved through a nest of sieves and the percentage by mass of material passing each sieve is determined. The results of this test show the level of mechanical interlock between the particles, a good indicator of how the material will perform once it has been compacted. See Section 2.3 for more details. The grading of these materials is strictly controlled to be within prescribed envelopes. The Standard Specifications set addition requirements such as:

- The **target grading** after compaction shall be as near as possible to the mean of the specified grading envelope.
- For **38 (37.5) mm maximum size aggregate**:
 - Percentage passing the 0.075 mm sieve shall be between 7% and 9%.
 - Percentage passing the 0.425 mm sieve shall not exceed 22%.
 - Fraction passing the 2 mm sieve shall not exceed 34%.



Report the Test Method

When test results are reported, the test method used must be stated.

South African Pavement Engineering Manual

Chapter 3: Materials Testing

Table 6. Test Requirements for G1, G2 and G3 Materials

Property and Test	Test Method ¹	Comments	Chapter Reference
Deleterious materials²: pH Electrical conductivity Sulphate tests Visual inspection	TMH1 A20 TMH1 A21T (SANS 3001-GR32)	- Use argillaceous rocks with caution. - Check pH and electrical conductivity as to whether treatment with lime is required. - Check sulphate content - Mica, if in quantities that can be easily seen, can affect compactibility.	3.2.6
Strength and Durability 10% FACT, wet & dry Aggregate Crushing Value (ACV) Soundness (magnesium sulphate test) Ethylene glycol tests	SANS 3001-AG10 SANS 3001-AG10 SABS 5839 (SANS 3001-AG12) SANS 3001-AG14 & 15	- For crushed stone base (G3 and better) and aggregates, strength tests are only performed on the minus 14 mm plus 10 mm fraction. - For durability, the wet/dry ratio is normally required to be greater than 0.75.	3.2.5 3.2.7 3.2.7 3.2.8
Mechanical interlock Grading: sieve analysis	SANS 3001-GR1 SANS 3001-GR2	- Gradings are strictly controlled to be within the prescribed envelopes. - Additional requirements on various individual sieve sizes. - The coarse sand fraction is also controlled.	3.2.1
Particle shape Flakiness No. of fractured faces	SANS 3001-AG4	- Flakiness index controlled on 2 aggregate fractions. - Number of fractured faces dependent on whether G1, or G2 and G3.	3.2.2
Plasticity Atterberg Limits	SANS 3001-GR10 SANS 3001-GR12	- Strict limits are set for Atterberg Limits, which vary between G1, G2, and G3 quality aggregates. - There are also plasticity index requirements on the minus 0.075 mm fraction.	3.2.3
Bearing strength and swell (G2 & G3) CBR CBR swell	SANS 3001-GR40	CBR and CBR swell requirements are set for G2 and G3 quality materials in TRH14.	3.2.4
Density standards	SANS 3001-AG22 (G1) SANS 3001-AG20 SANS 3001-AG21	Apparent density of crushed stone base (AD-CS) is used as the standard instead of maximum dry density for G1 materials and bulk density is used for G2 materials.	3.2.9
Field density Nuclear Gauge Sand Replacement	SANS 3001-NG5 SANS 3001-NG35	- Nuclear gauge considered the reference test for measuring density. - Sand replacement only used for certain applications.	2.7.1 2.7.2

Note

1. SANS test method in brackets will be the new SANS 3001 number when published.
2. Deleterious materials have sulphides, soluble salts and mica.

3.2.2 Flakiness Index (SANS 3001-AG4)

This test is carried out by determining the percentage of the total mass of the aggregate that passes through slots of a specified width in a metal plate. The Standard Specifications specify that the test should be carried out on two fractions of the aggregate, on the fraction passing 28 mm and retained on 20 mm, and the passing 20 mm retained on 14 mm fraction. The apparatus is shown in Figure 10.

The sample is also visually examined for fractured faces. The Standard Specifications specify that all the faces of G1 quality aggregate should be fractured, while 50% of G2 and G3 quality aggregate retained on the 5 mm sieve should have fractured faces.

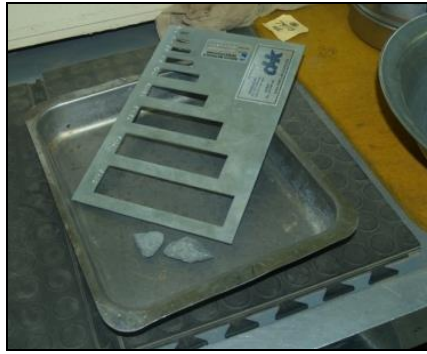


Figure 10. Flakiness Index Apparatus

3.2.3 Atterberg Limit Testing (SANS 3001–GR10)

Atterberg Limits are carried out to determine the plasticity of aggregates used in subbase and base layers. The test, which determines the Liquid Limit (LL), Plasticity Index (PI), and Linear Shrinkage (LS) of the material, is described in more detail earlier in Section 2.5. Note that the Standard Specifications require the test to be done on two fractions, the fraction passing the 0.425 mm sieve as well as the fraction passing the 0.075 mm sieve.

3.2.4 CBR Testing (SANS 3001–GR40)

The CBR test is used to assess the bearing strength of aggregates used in subbase and base layers. The CBR Swell is also determined as part of this test and provides an indication of changes in volume when the material is soaked. This test is not specified for G1, G2, or G3 quality materials in the Standard Specifications, and is only recommended for G2 and G3 materials in TRH14. See Section 2.8 for more details.

3.2.5 ACV and 10% FACT Tests (SANS 3001–AG10)

This test assesses the strength properties of aggregates. The basic difference between the ACV and the 10% FACT is that the ACV determines the percent of fines produced under a prescribed load and the 10% FACT determines the load necessary to produce 10% fines. The first point in the test carried out at a load of 400 kN gives the ACV value. The apparatus is shown in Figure 11. While the Standard Specifications give a range of minimum 10% FACT strengths based on rock type varying from 110 kN to 200 kN, it is recommended that for base materials, strengths in excess of 200 kN should be targeted. The ACV gives a less reliable indication of the strength of weaker materials (30% and greater), therefore the 10% FACT is preferred for weaker materials.



10% FACT and ACV Hints

ACV testing is preferable for hard materials. More reliable indications are obtained on softer materials when 10% FACT testing is used.



Figure 11. ACV and 10% FACT Apparatus

The wet 10% FACT test is carried out as part of the normal 10% FACT test to assess the durability of aggregates. The test is undertaken on soaked replicate samples of aggregate, and the ACV values, dry and soaked, are compared. A wet/dry ratio greater than 75% indicates satisfactory durability.

3.2.6 pH and Electrical Conductivity Tests (TMH1 A20 and A21T)

pH and electrical conductivity tests are carried out on aggregates used in bases and subbases to assess whether levels of acidity and soluble salts could be detrimental.

These tests are affected by the condition of the test apparatus and are currently being revised to provide more consistent and reliable results. They should be published in 2015 as a single test SANS 3001-GR32.

3.2.7 Soundness of Aggregates Test (SABS 5839)

The test is used to evaluate durability, and in particular, potential break down under traffic where both the fines and plasticity increase with time. The test consists of soaking an aggregate sample for five 16 hour cycles in a magnesium sulphate solution. The loss of material for the individual fractions and the total coarse and fine fractions are recorded. The performance of the aggregate is evaluated based on the overall loss for the sample.

This test will be republished as SANS 3001-AG12.

3.2.8 Ethylene Glycol Soak Tests (SANS 3001-AG14 & 15)

Two ethylene glycol soak tests are used to check the durability of the Basic Crystalline group of rocks. These tests show 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. The Ethylene Glycol Durability Index test (AG14) consists of soaking rock fragments in ethylene glycol, and observing any deterioration daily. A durability index is obtained by adding the "disintegration classification", which indicates the severity of disintegration, to the "time classification", which indicates the number of days taken for the most severe effect to occur.

In the other test (AG15), rock fragments are soaked in ethylene glycol before being subjected to the 10% FACT test. The load to generate 10% fines of the soaked aggregate is expressed as a ratio of the load required to generate 10% fines in the soaked sample.

3.2.9 Compaction Tests

The performance of an unbound granular base layer depends to a large extent on the degree to which it is compacted. Evaluation of field compaction testing is carried out with a nuclear gauge using direct transmission. Note should be taken regarding the interpretation of these results, as covered earlier in Section 2.7. Extra care should be exercised when driving in the spike to enable the probe to be inserted in the layer, so as to disturb the surrounding compacted layer as little as possible. In some cases, it is preferable to drill this hole to reduce the disturbance that affects the accuracy of the readings. Careless removal of the drill-bit, however, can lead to de-densification of the layer.

Compaction of pavement layers is calculated using the field density as a percentage of a reference density, which could be the apparent density of crushed stone base, the bulk density or the maximum dry density:

- The **apparent density of crushed stone** (AD-CS) (SANS 3001-AG22) is the reference for G1 quality bases specified in the Standard Specifications. This test differs from the AD determined in SANS 3001-AG20 and AG21 in that not all the permeable (surface) voids are excluded. Thus the values of apparent density of crushed stone base using SANS 3001-AG22 lie between the AD and the BD using SANS 3001-AG20 and AG21.
- The **bulk density** (BD) is the density of aggregate particles expressed as the mass of the aggregate particles divided by the volume of the aggregate particles including the impermeable (internal) and permeable (surface) voids, but excluding the inter-particle voids. The bulk density is used as a reference for G2 or G3 quality materials, and was known as the bulk relative density (BRD).
- The **maximum dry density** (MDD) is the dry density value of the material tested using the method specified in SANS 3001-GR30, determined by the peak of the compaction curve. The MDD is the reference method for G4 and lesser quality materials.



AD vs BD (and ARD and BRD)

The apparent density of crushed stone (AD-CS) is the reference density for G1s, and the bulk density (BD) for G2s and G3s.

The AD and BD used to be known as the ARD and BRD (apparent and bulk relative density). In line with international practice, the term "relative" has been dropped.

- The **apparent density** (AD) is the density of aggregate particles expressed as the mass of the aggregate particles divided by the volume of the aggregate particles including impermeable (internal) voids, but excluding permeable (surface) and inter-particle voids. This value is not used as a reference density, but gives an indication of the specific gravity or relative density of an aggregate.

The apparent and bulk densities are determined on two fractions of aggregate, using two different test methods:

- > 5 mm: SANS 3001–AG20
- < 5 mm: SANS 2001–AG21

3.3 Tests on Aggregates Used in Waterbound Macadam

Testing of the aggregates used in waterbound macadam pavement layers is similar to that of G1, G2 and G3 graded aggregates, and includes:

- Grading
- Flakiness
- 10% FACT
- Aggregate crushing value
- Atterberg limits on the fine aggregate fraction
- Durability tests
 - 10% FACT (wet)
 - Ethylene Glycol Soak Test

While the minimum compaction requirements of waterbound macadam are specified, usually between 86% and 90% of ARD, the measurement of in situ/compacted density in such coarse materials is highly problematic. Using a nuclear gauge it is not possible to drive in the spike to produce a hole for the probe without disturbing the layer, while drilling through the layer is also impractical. Sand replacement tests require the excavation of a large hole through the layer and in the non-cohesive material with large aggregate particles this is also not practical. Subjective judgement is therefore often used to control compaction of waterbound macadam layers. Visual observation of the movement of the large single sized aggregate (or lack thereof) under the roller, before the addition of the sand, gives the best indication of maximum density.



Waterbound Macadam

These pavement layers consist of large stones with fine material washed into the interstices between the large stones.

4. TESTS ON BITUMINOUS MATERIALS

Bituminous materials are materials that are treated with bitumen, either as hot mix asphalt or as a stabilized material. Bituminous materials are some of the most expensive and behaviourally complex materials used in pavement construction. Consequently, there are many tests used for these materials. This section covers the tests used for:

- Bituminous binders
- Hot mix asphalt
- Aggregates for bituminous materials
- Cold mix asphalt
- Surfacing seals
- Primes, precoating and tack coats
- Bitumen Stabilized Materials (BSMs)



Quality Control for Bituminous Materials

Quality control during construction of layers with bituminous materials is discussed in Chapter 13, in the following sections:

- Section 5: **Bitumen Stabilized**
- Section 6: **Asphalt**
- Section 7: **Spray Seals**

Standards applicable to bituminous materials are covered in Chapter 4: 4.

4.1 Tests on Bituminous Binders

Tests required for bituminous binders vary according to the type of binder, as summarised in Table 7. The tests listed are routinely carried out to ensure compliance with the relevant specification. Other properties of bitumen not necessarily specified are often monitored to provide users with information vital for correct application or to assist in the formulation of additions or amendments to specifications. Examples are:

- **Density** determination to permit conversion of mass to volume in calculations.
- **Viscosities** measured at high temperatures to ensure the establishment of correct application temperatures.
- **Force-ductility** tests to assess the energy absorbed during the extension of elastomer binders

SANS specifications require that sampling of **bitumen** and **bitumen emulsions** be carried out in accordance with ASTM D140 and any additional requirements of TMH5 to determine whether a lot complies with the appropriate requirements of the specification.

The procedures for sampling at various operational situations are comprehensively covered in Sabita Manual 25 (2005).

All **modified binders** should be sampled and prepared in accordance with the procedures set out in TG1 Method MB-1: Sampling of modified binders and MB-2: Sample preparation.



Behaviour of Bitumens

A good reference for an understanding of bitumen, what it comprises and how it behaves, is the **Shell Bitumen Handbook** (2003). Fifth Edition, Thomas Telford Publishing, London, UK.

The following tests are carried out to assess the suitability of **rubber crumbs** for use in bitumen-rubber binders and are described in detail in TG1:

- Particle size distribution and loose fibre content of rubber crumbs: MB-14
- Resilience of rubber crumbs: MB-15
- Bulk density of rubber crumbs: MB-16

4.1.1 Penetration Grade Bitumen

Penetration grade bitumen is classified by its penetration, and is commonly supplied in the following grades:

- 35/50 pen
- 50/70 pen
- 70/100 pen
- 150/200 pen

Typically, the selection of penetration grade bitumens is made on the basis of climate, traffic volumes and speed, and aggregate shape. Higher values of penetration indicate softer consistency. The tests used for penetration grade



Report the Test Method

When test results are reported, the test method used must be stated.

bitumens are listed in Table 7 and discussed below.

Table 7. Tests Carried Out on Bituminous Binders

Binder Type	Property Tested	Test	Chapter Reference
Penetration Grade Bitumen	Penetration Softening Point Dynamic Viscosity (at 60°C and 135°C) Flash Point Rolling Thin Film Oven Test (RTFOT) n-Heptane/Xylene Spot test	EN 1426 ASTM D36 ASTM D4402 ASTM D92 ASTM D2872 AASHTO T102	4.1.1
Cutback bitumen	Kinematic viscosity Distillation test Flash Point Percentage Water Penetration (on residue of distillation) Viscosity on residue from distillation	ASTM D2170 ASTM D4402 ASTM D93 ASTM D95 ASTM D402 ASTM D4402	4.1.2 4.1.2 4.1.4 4.1.1 4.1.1
Bitumen emulsions	Water content Particle charge: cationic Saybolt Furol viscosity Coagulation value test Sieve test Sedimentation test	ASTM D244 ASTM D244 ¹ ASTM D244 SANS 4001-BT3 ² IP 91 SANS 4001-BT3 ²	4.1.3
Modified binders	Flash Point Modified rolling thin film oven test Elastic recovery of polymer modified binders by ductilometer Torsional recovery of polymer modified binders Storage stability of polymer modified binders Modified Vialit adhesion test Pull out test method for surfacing aggregate Pliers test for assessment of adhesion properties Ball penetration and resilience of bitumen-rubber blends Compression recovery of bitumen-rubber binders Flow test for bitumen-rubber binders Dynamic viscosity of bitumen-rubber binders Softening point of modified binders by ring and ball method Dynamic (apparent) viscosity of polymer modified binders	ASTM D93 MB-3 ³ MB-4 MB-5 MB-6 MB-7 MB-8 MB-9 MB-10 MB-11 MB-12 MB-13 MB-17 MB-18	4.1.4
Modified Bitumen Emulsions	Recovery of residue of modified bitumen emulsions Viscosity of modified bitumen emulsions by means of the Saybolt Furol viscosity Water content of modified bitumen emulsions Residue on sieving of modified bitumen emulsions Particle charge of modified bitumen emulsions	MB-20 MB-21 MB-22 MB-23 MB-24	4.1.5
Precoating fluids	Saybolt Furol viscosity Distillation test Dynamic viscosity Stripping test	ASTM D244 ASTM D402 ASTM D4402 Riedel & Weber (TMH1 B11)	4.1.6

Notes:

1. As modified in SANS 4001-BT4.
2. As modified in SANS 4001-BT3 or SANS 4001-BT4.
3. Test methods designated "MB" are from TG1.

(i) Penetration Test (EN 1426)

This test measures the relative hardness or consistency of bitumen at 25 °C, representing an average in-service temperature. The value is used to classify the bitumen into standard penetration ranges in accordance with SANS 4001-BT1.

The penetration value of a bitumen is defined as the distance in tenths of a millimetre (dmm) that a standard needle, pre-treated in oleic acid will penetrate into the bitumen under a load of 100g applied for five seconds at 25 °C. The test equipment is shown in Figure 12.



Pen Test

The penetration of a bitumen is colloquially termed its "pen".

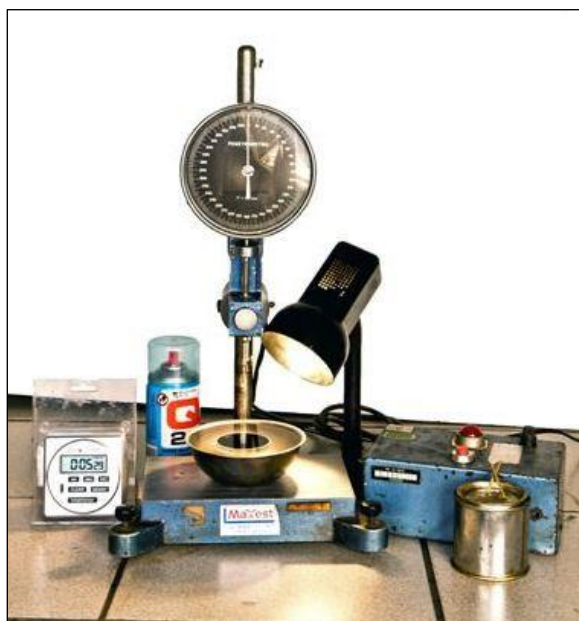


Figure 12. Penetration Test Equipment

(ii) Softening Point Test (ASTM D36)

This is another test of consistency which determines the temperature at which the bitumen is transformed from a solid to a liquid phase. For the majority of bitumens, this viscosity value is in the region of 1200 Pa.s, which is equivalent to a penetration of 800 dmm. The results of this test also indicate the capacity of a particular bitumen to perform adequately at high in-service temperatures.

Also referred to as the Ring-and-Ball Softening Point test, this test determines the temperature at which a bitumen disc of controlled dimensions softens sufficiently to allow a steel ball, initially placed on the surface, to sink through the disc to a further prescribed distance. The equipment is shown in Figure 13.



Figure 13. Ring and Ball Test Equipment

(iii) Dynamic Viscosity Test (ASTM D4402)

Viscosity, i.e., the resistance to flow or shear, is a fundamental characteristic of bitumen. The resistance to flow or shear stress is governed by the internal friction and can be measured and expressed in units of stress required to overcome this friction. For bitumen, the viscosity is specified at both 60 °C and 135 °C, which provides a means of assessing consistency at high in-service and application temperatures, respectively. The relationship of viscosity and temperature can be used to determine the correct temperatures for pumping, spraying, mixing and compaction of asphalt mixes.

The (dynamic) viscosity is determined by measuring the torque required to rotate a spindle which is immersed in bitumen. The viscometer used in South Africa is the Brookfield model RV with Thermosel system (Figure 14) using SC-4 type spindles. The SI unit of dynamic viscosity is the Pascal second (Pa.s).



Figure 14. Brookfield Viscometer

(iv) Rolling Thin Film Oven Test, RTFOT (ASTM D2872)

RTFOT exposes bitumen to ageing and hardening due to the effect of heat and oxidation in the presence of air as would typically occur in a hot mix asphalt manufacturing plant. The residue of ageing is then tested to gauge its resistance to age-hardening. The procedure does not, however, purport to simulate long term in-service ageing.

In the RTFOT, illustrated in Figure 15, a series of glass containers rotates in a vertical plane so that a fresh surface of bitumen is continuously being exposed to air. This exposure (at 163 °C) is continued for 75 minutes and a controlled flow of air is blown over the surface of the bitumen from a single nozzle.

At the end of the test, the change in mass, viscosity, softening point and penetration is assessed in terms of the requirements of the relevant specifications.

(v) n-Heptane/Xylene Spot Test (AASHTO T102)

The n-Heptane/Xylene spot test assesses the potential for a binder to be susceptible to oxidation, thereby having an adverse effect on the durability of the bitumen during service on the road. This test is not relevant for modified binders. It is useful in identifying overheated or unbalanced bitumen.



Oxidation

Oxidation causes bitumen to harden. Penetration decreases and Ring and Ball Softening Point increases as a result.

The spot test is carried out by dropping a solution of bitumen in prescribed mixtures of n-heptane and xylene onto a filter paper. The test is negative when a uniformly brown stain is formed. Otherwise the test is positive. The test is shown in Figure 16.

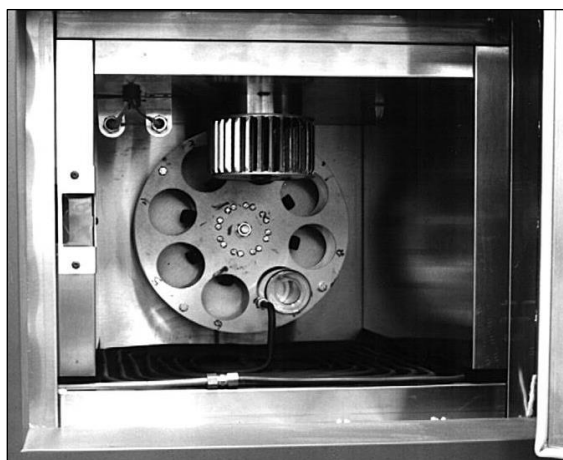


Figure 15. Thin Film Oven Test (RTFOT)



Figure 16. N-Heptane/Xylene Spot Test

4.1.2 Cutback Bitumen

Cutback bitumens consist of bitumen to which a solvent is added. The solvent reduces the viscosity of the binder. Cutback bitumen is used in applications where a low initial viscosity is required, such as in the construction of sand seals.

The tests used for cutback bitumens are listed in Table 7 and discussed below.

(i) Kinematic Viscosity Test (ASTM D2170)

This test of consistency is used to classify cutback binders. Cutback bitumens are classified by their kinematic viscosity at 60 °C, expressed in centistokes (cSt). The lower limit of the viscosity range is used in the grade designation, while the upper limit is double this lower figure, e.g., MC-30 has a viscosity at 60 °C in the range of 30 to 60 cSt. As is the case with penetration grade bitumen, the temperature/viscosity relationships of cutback bitumens can be used to determine the correct spraying, mixing and pumping temperatures.

The measurement of kinematic viscosity is made by timing the flow of the cutback bitumen through a glass U-tube capillary viscometer at a given temperature. The testing equipment is shown in Figure 17. Each viscometer is calibrated. The product of efflux time and viscometer calibration factor gives the kinematic viscosity in Stokes.



Figure 17. Kinematic Viscosity Testing Equipment

(ii) Distillation Test (ASTM D402)

This procedure measures the amount of the more volatile constituents in cutback bitumen and, hence gives an indication of the rate at which the binder will cure through the evaporation of volatile fractions. The properties of the residue after distillation are not necessarily characteristic of the bitumen used in the original mixture, nor of the residue which may be left at any particular time after field application of the cutback bituminous product.

The proportion and type of solvent present in cutback bitumen is determined by heating the material, condensing the vapours and noting the volume of the condensate collected at various specified temperatures up to 360 °C. The undistilled portion remaining constitutes the binder content of the cutback.

4.1.3 Bitumen Emulsion

Bitumen emulsion is made by emulsifying penetration grade bitumen. The manufacturing process is done in a specialized plant, where heated bitumen and water is intimately mixed together in a colloid mill. An emulsifying agent is added during the mixing process to stabilize the emulsion. Two basic types of bitumen emulsion are supplied:

- **Anionic emulsions:** bitumen particles are negatively charged in an alkaline aqueous phase
- **Cationic emulsions:** positively charged bitumen particles in an acidic aqueous phase.

The tests used for bitumen emulsion are listed in Table 7 and discussed below.

(i) Water Content Test (ASTM D244)

This test method measures the amount of water present in the emulsified bitumen, as distinguished from either bitumen or cutters. Bitumen emulsions may contain up to 40% of water by volume and it is essential that the quantity of residual bitumen (which may include cutters) actually applied to the road surface is accurately determined.

The water content is determined by means of a distillation procedure using equipment commonly referred to as the Dean and Stark apparatus, illustrated in Figure 18. An organic liquid immiscible with water (usually xylol) is added to the sample and the flask is heated. The organic liquid distils into the receiving flask, carrying with it the water, which then separates into a lower layer. The volume of water is measured and, by difference, the residual binder content is determined.



Figure 18. Dean and Stark Apparatus for Water Content Test

(ii) Particle Charge Test (SANS 4001-BT4)

This test distinguishes between cationic and anionic emulsions, and is only included in the specification for cationic emulsions. Two electrodes are immersed in a sample of emulsion and connected to a low power direct current source. If, at the end of the specified period, bitumen deposits are observed on the cathode, i.e., the electrode connected to the negative side of the current source, the emulsion is identified as a cationic bitumen emulsion. Conversely if the bitumen deposits are observed on the anode, the emulsion is identified as an anionic emulsion.



Cationic and Anionic Emulsions

Cationic emulsions contain positively charged bitumen particles, whereas anionic emulsions contain negatively charged bitumen particles.

(iii) Saybolt Furol Viscosity Test for Emulsions (ASTM D244)

The viscosity of an emulsion is monitored by means of this test to ensure that its flow properties are appropriate to the application, e.g., steep gradients and high cross fall.

The viscosity of bitumen emulsion is measured by means of the Saybolt Furol Viscometer. In this test, the time of efflux of a specified volume of emulsion through the standard orifice is measured at 50 °C.

(iv) Coagulation Value Test (SANS 4001-BT4 and BT3)

This test determines the ability of a stable mix grade emulsion to not break prematurely in the presence of cement or lime. Emulsion is stirred into a cement paste with the further addition of water. The materials are then washed through a 180 μm sieve. The mass of materials retained expressed as a fraction of the binder in the emulsion sample used is the coagulation value.

(v) Residue on Sieving Test (SANS 4001-BT4 and BT3)

This test assesses the quality of an emulsion in terms of bitumen particle size. The bitumen particles in a good quality emulsion should be so small that virtually all pass through the mesh of a 150 μm sieve.

A quantity of emulsion is poured through a very fine sieve. After rinsing, the mass of bitumen in the form of large particles, strings or lumps retained on the sieve is determined. The equipment for the test is shown in Figure 19.



Figure 19. Sieve Test for Emulsions

(vi) Sedimentation Test (SANS 4001-BT3 and BT4)

This test ensures that the emulsion possesses adequate storage stability, especially when packaged in drums.

A sample of emulsion is placed in a jar, which is centrifuged for a specified time at a specified speed. After the centrifuge stops, no excessive sedimentation should occur. The degree of sedimentation is determined by rotating the jar end over end in a special apparatus until the sediment is re-dispersed in an added soap solution.

4.1.4 Modified Binders

Bitumen is modified using various modifying agents, the purpose of which is to offer improved performance compared to conventional binders. A range of benefits that may be derived from binder modification, as well as a list of the most commonly used modifiers is included in TG1. The tests used for modified binders are listed in Table 7 and discussed below. The modified binder methods are included in TG1.

(i) Flash Point (ASTM D93)

The flash point of a volatile liquid is the lowest temperature at which it can vaporize to form an ignitable mixture in air. The flash point is used in shipping and safety regulations to define flammable and combustible materials.

In the closed cup flash point test, a brass test cup is filled with a test specimen and fitted with a cover. The sample is heated and stirred at specified rates and an ignition source is directed into the cup at regular intervals with simultaneous interruption of stirring until a flash that spreads throughout the inside of the cup is seen. The corresponding temperature is its flash point. The test is shown in Figure 20.

(ii) Modified Rolling Thin Film Oven Test (MB-3)

This test has a similar purpose and procedure to that described under the Rolling Thin Film Oven Test carried out on penetration grade bitumen (Section 4.1.1(iv)). To deal with the complex flow characteristics of modified binders, a larger quantity of binder is used and metal treatment bottles with internal rollers are employed.

(iii) Elastic Recovery of Polymer Modified Binders by Ductilometer (MB-4)

This method is used to assess the elastic recovery properties of a polymer modified binder. Moulded specimens are extended for a distance of 200 mm in a ductilometer under controlled conditions. The elongated thread is cut and after one hour the extent of recovery of the thread is measured. The test is shown in Figure 21. The test is similar to that used for conventional binders, except that the elongated thread is cut.

(iv) Torsional Recovery of Polymer Modified Binders (MB-5)

This test provides a simple means of determining the elastic recovery properties of a polymer-modified binder. An aluminium bolt, embedded in a cup of modified binder is manually rotated through 180 degrees over a period of 10 seconds. The recovered angle in degrees is measured after 30 seconds and expressed as a percentage of 180 degrees. The test is shown in Figure 22.



Figure 20. Flash Point Test



Figure 21. Ductility Tests

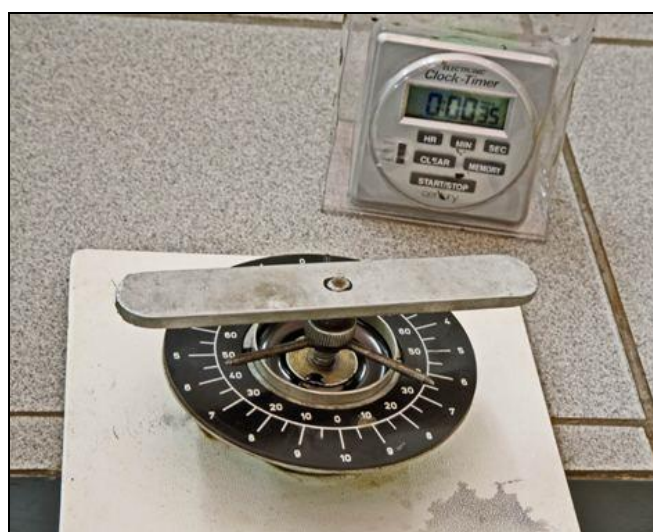


Figure 22. Torsional Recovery Test

(v) Storage Stability of Polymer Modified Binders (MB-6)

This method measures the resistance of the modified binder to segregation between the modifying agent and the base bitumen during hot storage.

The test is performed by measuring the softening points of the upper and lower third of a cylindrical specimen that has been stored in a heated oven for three days, in accordance with method ASTM D36. The difference in softening point is recorded in °C. The apparatus is shown in Figure 23.



Figure 23. Storage Stability Test

(vi) Modified Vialit Adhesion Test (MB-7)

The test is used to assess the adhesion of modified binders to aggregates. This test does not provide reliable results for decision making, but it can be used as a rough guide for comparing the adhesion properties of different modified binders.



Modified Vialit Adhesion Test

This test does not provide reliable results for decision making.

The test method involves placing quartzite aggregates shoulder to shoulder on a film of hot modified binder on a metal plate. After conditioning of the plate at the test temperature of either 5 °C or 25 °C, it is turned with the aggregates on the bottom face and a steel ball of prescribed mass is dropped from 500 mm to strike the centre of the plate. The degree of retention is calculated as the percentage of aggregates that are retained on the plate.

This test method may also be adapted to simulate site conditions, for example, aggregate, temperature, precoating and binder application rate.

(vii) Pull Out Test Method for Surfacing Aggregate (MB-8)

The test is used to determine whether aggregates in a surfacing constructed with modified binder are sufficiently held by the binder to allow opening to traffic.

To do this test, the average force required to dislodge a number of stones from the surfacing, corrected for temperature, where appropriate, is measured. This force is compared to recommended minimum requirements for a set of conditions related to traffic road geometry and season.

(viii) Pliers Test for Assessment of Adhesion Properties (MB-9)

This test is used as a rapid site check of the effective wetting and adhesive characteristics of the binder.

The test is done on site midway and at the end of a spray run. Immediately before the aggregate spreading operation, a number of pre-coated stones are dropped onto the sprayed binder, left to remain for a minute and picked up cleanly. A visual examination of the binder film adhering to the surface of the stones is carried out to

assess the degree of adhesion and correct binder viscosity. The adhesion characteristics, i.e., how well the chips adhere to the binder, are assessed using the guidelines given in the test method. As a preliminary guide, the test can be performed in the laboratory. A film of the binder is applied on a suitable surface, and the same procedure is followed as that used on site.

(ix) Ball Penetration and Resilience of Bitumen-Rubber Blends (MB-10)

This test is similar to the penetration test as it measures the relative hardness and consistency of bitumen rubber blends at 25 °C. The penetration of a standard ball into non-aged and oven-aged binder as well as the rebound recovery is measured. A value of resilience is calculated from the results of the test.

(x) Compression Recovery of Bitumen-Rubber Binders (MB-11)

The compression recovery of bitumen-rubber blends is an indication of the contribution of the rubber crumbs to the elasticity of the binder. To measure this, the elastic recovery of a bitumen-rubber cylinder is measured after it has been compressed to half its original height. The recovery is defined as the height of the recovered specimen, expressed as a percentage of the original height. The test is illustrated in Figure 24.

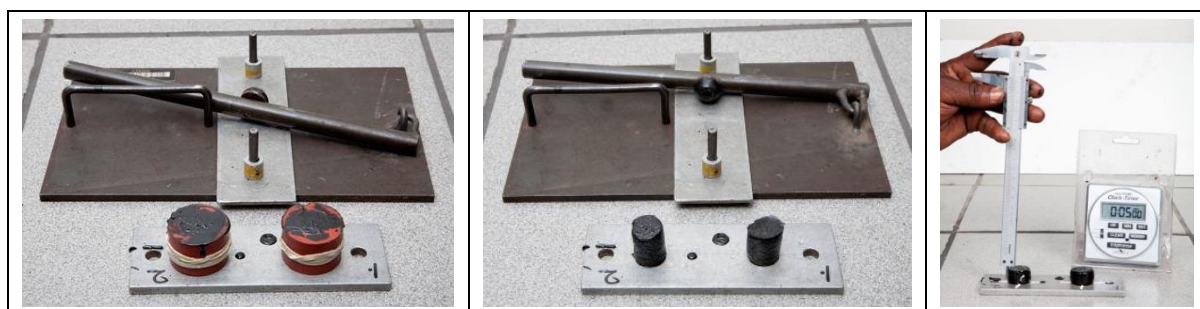


Figure 24. Compression Recover Test Equipment

(xi) Flow Test for Bitumen-Rubber Binders (MB-12)

The test gives an indication of the flow characteristics or consistency of bitumen-rubber at temperatures comparable to the upper operating temperatures in a pavement. The flow distance of a specimen placed on a smooth metal plate inclined at an angle of 35° and subjected to a temperature of 60 °C for four hours is reported as the flow (mm). This test is shown in Figure 25.



Figure 25. Flow Test

(xii) Dynamic Viscosity of Bitumen-Rubber Binders (MB-13)

The viscosity of the binder is tested in a laboratory at its recommended spray temperature or on site before, during and after spraying to ensure that it is sprayable without congestion of the pump/spray bar system.

The test is conducted with a hand-held, battery operated rotary viscometer. The sample is taken on site during spraying operations, or on one prepared in the laboratory at the recommended spray temperature.

(xiii) Softening Point of Modified Bitumen (MB-17)

See Section 4.1.1(ii) (ASTM D36) for significance and method.

(xiv) Dynamic Viscosity of Polymer Modified Bitumen (MB-18)

See Section 4.1.1(iii) (ASTM D4402) for significance and method.

4.1.5 Tests on Modified Bitumen Emulsions

Modified bitumen emulsions are emulsion where modified bitumen is used rather than penetration grade bitumens. The tests used on modified bitumen emulsion are listed in Table 7 and listed below.

(i) Recovery of Residue of Modified Bitumen Emulsion (MB-20)

The residue recovered in this procedure is representative of the modified binder on the road after the evaporation of fluxing oils. It is subjected to further testing with other tests.

The recovery is performed either with a rotary evaporator (Figure 26) or a simple evaporation method using a Bunsen burner, during which the emulsion is heated and the residue of modified binder obtained. The simple method is more suitable for site use.



Figure 26. Binder Recovery Test

(ii) Water Content of Modified Bitumen Emulsions (MB-22)

See Section 4.1.3(i) (ASTM D244) for significance and method.

(iii) Viscosity of Modified Bitumen Emulsions by Means of the Saybolt-Furol Viscometer (MB-21)

See Section 4.1.3(iii) (ASTM D244) for significance and method.

(iv) Residue on Sieving of Modified Bitumen Emulsions (MB-23)

See Section 4.1.3(v) (SANS 309, soon to be updated to SANS 4001-BT4) for significance and method.

(v) Particle Charge of Modified Bitumen Emulsion (MB-24)

This test distinguishes between cationic and anionic emulsions. SANS 548 (soon to be updated to SANS 4001-BT3), refers to the method described in ASTM D244 (Section 4.1.3(i)), is followed with the exception that thickness of the electrode is 0.71 mm. Two electrodes are immersed in a sample of emulsion and connected to a low power direct current source. If, at the end of the specified period, bitumen deposits are observed on the cathode, i.e., the electrode connected to the negative side of the current source, the emulsion is identified as a cationic bitumen emulsion. If the bitumen deposits are on the anode, the emulsion is an anionic bitumen.

4.1.6 Precoating Fluids

Precoating fluids consist of low viscosity bitumen based products containing petroleum cutters and a chemical adhesion agent. They are used to precoat surfacing aggregates to improve the adhesion of the aggregate to the bituminous binder.

The tests used on precoating fluids are listed in Table 7 and discussed below.

(i) Viscosity Test (ASTM D244)

The viscosity of a precoating fluid is monitored to ensure that its flow properties are such as to ensure adequate coating of surfacing aggregates that may be damp or dusty. The viscosity of the precoating fluid is measured by means of the Saybolt Furol viscometer. In this test, the time of efflux of a specified volume of emulsion through the standard orifice is measured at 50 °C. See Section 4.1.3(iii).

(ii) Distillation Test (ASTM D402)

This procedure measures the amount of the more volatile constituents. This gives an indication of the rate at which the precoating fluid will cure through the evaporation of volatile fractions, thus leaving a non-tacky residual film on the surface of the aggregate, which enhances the adhesion of the aggregate to the binder.

The proportion and type of solvent present in the precoating fluid is determined by heating the material, condensing the vapours and noting the volume of the condensate collected at various specified temperatures up to 360 °C. The undistilled portion remaining constitutes the binder content of the cutback.

(iii) Bitumen Adhesion or Stripping Test (Riedel & Weber, TMH1 B11)

This test is conducted to assess the effectiveness of the precoating fluid to promote adhesion of the surfacing aggregate to binder compared to uncoated aggregate. This test is also used to assess binder adhesion to aggregates in the manufacture of asphalt, as well as adhesion of binder to chips used in surfacing seals. This test lacks in reliability and the results can only be regarded as indicative.

The adhesion of bitumen to stone aggregate is determined by boiling coated aggregate successively in distilled water and in increasing concentrations of sodium carbonate, numbered 0 to 9 and corresponding to 0 and 1 molar concentrations, respectively. The number of the concentration at which the bitumen strips to such an extent that it is no longer a film but only specks or droplets, is called the stripping value.



Riedel & Weber Stripping Test

This test does not provide reliable results and should only be used as an indication of the stripping potential.

4.2 Tests on Hot Mix Asphalt

Hot mix asphalt is made up of three primary component materials, which need to be tested:

- Bituminous binders
- Aggregates
- Fillers

Testing is also carried out on asphalt reclaimed from existing pavements (usually by milling) as well as from sources of discarded asphalt, such as found in the vicinity of asphalt plants. The material, known as reclaimed asphalt or "RA", is used in the manufacture of recycled asphalt mixes.



Asphalt Sections in this Manual

This section is closely related to:

- Chapter 2: **Pavement Composition and Behaviour**, Section 2.3.1
- Chapter 4: **Standards**, Section 4.2
- Chapter 9: **Materials Utilisation**, Section 10
- Chapter 10: **Pavement Design**, Section 7
- Chapter 12: **Construction Equipment and Method Guidelines**, Section 2.2, 3.11 and 4.1
- Chapter 13: **Quality Management**, Section 6
- Chapter 14: **Post-Construction**, Section 4.1

Testing for asphalt mixes are routinely carried out on:

- Component materials for **quality assurance**
- Component materials for **design**
- **Mix specimens** for:
 - Assessing volumetric properties
 - Quality assurance purposes
 - Measuring performance characteristics

4.2.1 Bituminous Binders

The testing of the bituminous binders used in hot mix asphalt is covered in Section 4.1.

4.2.2 Aggregates

Details of the test methods to determine the various properties of the aggregates used in hot mix asphalt as well as for rolled-in chips are summarised in Table 8. Many of the tests have been discussed earlier in this chapter.

(i) Polished Stone Value (SABS 5848)

This polished stone value (PSV) test is applicable to aggregates used for rolled-in chips for asphalt surfacings and for spray seals. It is also applicable to asphalt surfacings where the polishing properties of the aggregate play a major role in the macro surface texture, such Stone Mastic Asphalt (SMA), open-graded or semi open-graded mixes, and to a lesser extent, continuously graded asphalt mixes.

Specimens containing samples of the candidate aggregate are subjected to accelerated polishing in a specialised polishing machine using emery abrasive powders and water. Replicate polishing is also carried out on samples of PSV control aggregate. Both candidate specimens and specimens of the control aggregate are subjected to testing with a pendulum friction tester.

This test will be republished as SANS 3001-AG11.

(ii) Sand Equivalent (SANS 3001-AG5)

This test is used to determine the quantity of fine aggregates used in the manufacture of asphalt, or in bituminous slurry seals, and is illustrated in Figure 27.

The test sample consists of fine aggregate passing the 5 mm sieve. A measured quantity of the oven dried sample is transferred into a transparent cylinder. A solution consisting of calcium chloride, glycerine and formaldehyde diluted in water, known as the “working solution”, is added. After thorough shaking, a metal irrigator tube connected by rubber tubing to a container of the working solution is inserted to the bottom of the cylinder and is used to flush fines upwards, above the coarser sand particles. The irrigator is removed once the required level of solution in the cylinder has been reached. The cylinder and contents are then left to stand undisturbed. After 20 minutes, the level at the top of the fines suspension, known as the “fines reading” is read off. A weighted foot assembly is then lowered into the cylinder until it rests on top of the sand. The level of the indicator at the base of foot, the “sand reading”, is read off. The sand equivalent is calculated by expressing the “fines reading” as a percentage of the “sand reading”. High sand equivalent values thus indicate better quality fine aggregate compared to those with low sand equivalent values.

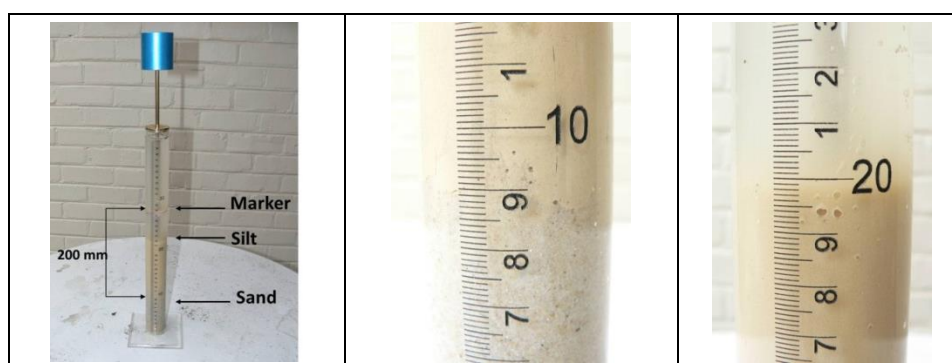


Figure 27. Sand Equivalent

Table 8. Test Requirements for Asphalt

Application	Test/Property	Test Method ¹	Chapter Reference
Aggregate	Grading	SANS 3001–AG1	2.3
	Flakiness	SANS 3001–AG4	3.2.2
	Polished stone value	SABS 5848 (SANS 3001–AG11)	4.2.2
	Sand equivalent	SANS 3001–AG5	4.2.2
	Water absorption	SANS 3001–AG20 & 21	4.2.2
	Bitumen adhesion	TMH1 B11	4.1.6
	ACV and 10% FACT	SANS 3001–AG10	3.2
	Clay lumps and friable particles	ASTM C142–97	4.2.2
	Ethylene Glycol Durability Test	SANS 3001–AG14	3.2
	Ethylene Glycol using 10% FACT	SANS 3001–AG15	3.2
Rolled in chips	Grading	SANS 3001–AG1	2.3
	ACV and 10% FACT	SANS 3001–AG10	3.2
	Polished stone value	SABS 5834 (SANS 3001–AG11)	4.2.2
Inert and active fillers in hot mix asphalt	Grading (% passing 0.075 mm)	SANS 3001–AG1	2.3
	Bulk density in toluene	BS 812	4.2.3
	Voids in compacted filler	BS 812	4.2.3
	Methylene Blue test	SANS 1243	4.2.3
Mix Components	Determine unit weight of aggregate	AASHTO T 19/T 19M-93	4.2.5
	Void content of fine aggregate	ASTM C1252	
Asphalt Mix	Make Marshall briquettes	SANS 3001–AS1	4.2.5
	Gyratory compaction	ASTM D6925–09	
	Marshall flow, stability and quotient	SANS 3001–AS2	
	Bulk relative density and void content of compacted asphalt	SANS 3001–AS10	
	Maximum voidless theoretical relative density of mixes and quantity of binder absorbed by aggregate (RICE)	SANS 3001–AS11	
	Soluble binder content and particle size analysis	SANS 3001–AS20	
	Immersion Index	TMH1 C5	
	Moisture content of asphalt	SANS 3001–AS23	
	Asphalt content by ignition method	(SANS 3001–AS21)	
	Hamburg Wheel-tracking Device (HWTD)	Tex-24-F	
	Indirect Tensile Strength (ITS) Test	ASTM D6931–07	
	Moisture Sensitivity Test (Modified Lottman)	AASHTO T283	
	Cantabro Abrasion Test	Standard Specifications DPG1	
	MMLS for permanent deformation and susceptibility to moisture damage	Stellenbosch University (will be SANS 3001-PD1)	
	Dynamic creep	CSIR RMT 004	
	Air permeability	TRH8 Appendix C	
	Coring of hot mix asphalt	No specific method	

Notes:

1. SANS test method in brackets will be the new SANS 3001 number when published.

(iii) Water Absorption (SANS 3001–AG20 and AG21)

The test is used to assess the quality of aggregates, with high water absorption values indicating material with relatively poor qualities.

Water absorption is determined using two separate tests:

- SANS 3001–AG20 on the fraction retained on the 5 mm sieve
- SANS 3001–AG21 on the fraction passing the 5 mm sieve

Water absorption is defined as the loss of mass between saturated surface dry and oven-dried aggregates, expressed as a percentage of the oven-dried mass. In both these tests, the respective samples are soaked in water for 24 hours before being brought to a saturated surface dry condition and then weighed. The samples are then oven-dried and reweighed. The weights of the saturated surface and oven-dried samples are used to calculate the water absorption of the aggregate.

(iv) Clay Lumps and Friable Particles (ASTM C142–97)

This test basically consists of a washed grading. The material is weighed dry then washed through a 0.075 mm sieve, dried and weighed again. During the washing process, the material is manipulated by hand to break down clay lumps and friable particles. The intention of this test is to assess the quality of fine aggregate, in particular that of natural sand, in the manufacture of asphalt or bituminous slurry seals, where further breakdown of clay lumps or friable material could occur during the mixing process.

4.2.3 Fillers

Filler comprises materials which substantially passes the 0.075 mm sieve, and consists of:

- **Inert fillers**, such as natural dust or rock-flour
- **Active fillers**, like hydrated lime or cement

Details of the test methods to determine the various properties of the fillers used in hot mix asphalt are summarised in Table 8, and are discussed below.

(i) Bulk Density in Toluene (BS 812)

This test is used to assess the volumetric properties of materials in the laboratory asphalt mix design stage, usually in the design of stone skeleton type mixes.

The test is carried out by weighing 10 g of the filler and submerging it in a measuring cylinder in toluene. The cylinder and contents are inverted several times to remove air bubbles before leaving it to stand for 6 hours, after which the bulk volume of the filler is read off. The bulk density of the filler in toluene is calculated using the mass of the filler (10 g) over its bulk volume.

(ii) Voids in Compacted Filler (BS 812)

This test is used to assess the volumetric properties of materials during the laboratory asphalt mix design stage, usually in the design of stone skeleton type mixes.

In the test, a sample of the filler is dried and placed in a steel cylinder. A specified compactive effort is applied to the sample using a steel plunger. The depth of the compacted filler is used to calculate its compacted dry void content.

(iii) Methylene Blue Test (SANS 1243)

This is a rapid qualitative test for determining whether the clay content of the fines of an aggregate contains deleterious swelling clay minerals, such as smectites, which could adversely affect the quality of the asphalt mix.

The test is carried out by dispersing a 1 g sample of material passing 0.075 mm in water. This is titrated with an indicator solution made by dissolving methylene blue in distilled water. The indicator solution is gradually added to the dispersion. After agitation, a drop of the dispersion is removed using a glass rod and dabbed onto a sheet of filter paper to form a blue spot. The indicator solution is added in increments of 0.5 ml. The dabbing procedure is repeated after each increment of the indicator until a definite blue halo appears around the spot. The quantity of methylene blue used to achieve the halo effect is recorded and used to calculate the methylene blue adsorption value (MBV).

4.2.4 Reclaimed Asphalt (RA)

Reclaimed asphalt (RA) is prepared for recycling by crushing and screening into two or three separate fractions. Typically the tests carried out on the fractionated RA consist of:

- Grading
- Binder content
- Recovered binder properties:
 - Penetration
 - Ring and ball softening point

For testing requirements on RA, refer to TRH21. In general terms, the level and frequency of testing depends to a large extent on the RA content of the recycled asphalt mixes. Testing of the aggregate properties, as well as the aged binder that forms part of the RA, becomes particularly important once 20% or more of the total asphalt mix consists of RA.



When to test RA

When 20% or more of the new mix is made up of RA, testing of the aggregate and aged binder is very important.

4.2.5 Tests on Mix Components and Mixes for Design

This section deals exclusively with tests on:

- Mix components for **design purposes**
- Asphalt mix specimens to assess **performance characteristics**

The tests on asphalt listed in Table 8 are routinely carried out to ensure that design objectives are met or job lots comply with the specifications. Other properties of asphalt, not necessarily specified, are often monitored for higher level analysis to provide the necessary information to ensure satisfactory performance.

(i) **Manufacture of Asphalt Briquettes for Marshall and Other Specialised Tests (SANS 3001-AS1)**

Compacted bituminous mixture specimens moulded by this procedure are used for various physical tests such as:

- Stability
- Flow
- Indirect tensile strength
- Fatigue
- Creep
- Modulus

Density and voids analyses are also conducted on specimens during mix design and to evaluate field compaction.

To manufacture the briquettes, asphalt mixtures prepared in the laboratory, or obtained from a plant or construction site, are moulded in a mould assembly through impact by means of a standard (mechanical) compaction hammer. The height of fall of the hammer is fixed and the number of blows on each face of the material in the mould is predetermined, depending of the use and application of the material. The method describes the method of specimen preparation, differentiating between laboratory mix samples (generally performed for design purposes) and plant mix or site samples, and makes provision for the use of reclaimed asphalt in the mixes being tested. Marshall compaction is shown in Figure 28.

(ii) **Unit Weight of Aggregate (AASHTO T 19/T 19M-93)**

These tests are performed to assess coarse aggregate packing characteristics to aid selecting aggregate proportions for the appropriate project mix type, i.e., stone or sand skeleton mixes or SMA, in accordance with the guidelines of the Bailey method of design. (TRB, 2002)

Procedures for determining both a compacted unit weight and loose unit weight are described in this method. For the compacted unit weight, a mould is filled in three equal layers, each layer being rodded evenly with 25 strokes of the tamping rod. For the loose unit weight, the aggregate is filled by a shovel or scoop to overflowing. In both cases the aggregates are levelled off so that any slight projections of the larger aggregates balance the larger voids below the rim of the mould. The unit weight is determined by the net mass of aggregate divided by the volume of the mould.



Bailey Method

The Bailey Method is used to evaluate the packing characteristics of aggregates. The coarse and fine fractions are evaluated separately and also as a blend, by volume as well as by mass.

(iii) **Fine Aggregate Angularity Test (ASTM C1252)**

This test, officially the "Uncompacted Void Content of Fine Aggregate Test", is an indirect measure of a fine aggregate's angularity, sphericity and surface texture. This test is used to gauge whether the blend of fine aggregate has sufficient angularity and texture to resist permanent deformation (rutting) for a given traffic level. It can also indicate the effect of the fine aggregate on the workability of a mixture.

The method describes the determination of the loose, uncompacted void content of a sample of fine aggregate. On a sample of known grading, the loose uncompacted void content is indicative of the relative angularity and surface texture of the sample. The higher the void content, the higher the assumed angularity and the rougher the surface. Three procedures are included for the measurement of void content. Two use graded fine aggregate (standard grading or as-received grading) and the other uses several individual size fractions for void content determinations.



Figure 28. Marshall Compaction



Figure 29. Marshall Stability and Flow Test

(iv) Marshall Flow, Stability and Quotient (SANS 3001–AS2)

Marshall stability and flow values, along with density and other volumetric properties, are used for laboratory mix design and evaluation of bituminous mixtures, often to gauge the resistance of the mix to permanent deformation. In addition, Marshall stability and flow may also be used to make relative assessments of effects of conditioning such as with water.

To do the tests, a Marshall briquette, preconditioned at 60 °C for 30 minutes, is inserted in a preheated breaking head assembly and loaded in a direction perpendicular to the cylindrical axis at a steady, predetermined rate. The load on the specimen and its deformation, or flow, is recorded. The ratio of stability to the flow is termed the “quotient”. The apparatus is shown in Figure 29.



Marshall for Bitumen-Rubber Mixes

The Marshall test is not suitable for mixes with bitumen-rubber. Refer to SABITA Manual 19 (1997) for alternative options.

(v) Bulk Density and Void Content of Compacted Asphalt (SANS 3001- AS10)

The bulk density (BD) is defined in Section 3.2.9. The results obtained from this test method are used to determine the unit weight of compacted asphalt briquettes, cores or block samples and to obtain the percentage air voids in the samples. These values in turn may be used to determine the relative degree of field compaction and volumetric properties required for design.

Three procedures are described for the determination of the volume of the test specimens, depending on the estimated surface voids expressed as the water absorption and the accessibility of the voids in the specimen:

1. For specimens with a **closed surface** (water absorption < 0.85%): saturated surface dry procedure.
2. For specimens with an **open or coarse surface** (water absorption between 0.85% and 15%): specimens are sealed with an elastomeric film covering.
3. For specimens with a **regular surface and geometric shape** that have void contents greater than 15% (water absorption > 15%): by direct measurement.

The bulk density, voids in the mix and voids in the mineral aggregate of the asphalt are determined by calculation. The equipment is shown in Figure 30.



Figure 30. Bulk Relative Density of Asphalt

(vi) Maximum Voidless Density and Quantity of Binder Absorbed by the Aggregate (SANS 3001–AS11)

This test, performed either on laboratory prepared samples or field samples, is used to calculate air voids in the compacted asphalt, the amount of bitumen absorbed by the aggregate and to provide target values for the compaction of asphalt layers. This test is often referred to as the RICE method.

Binder absorption is defined as the mass of binder, expressed as a percentage of the mass of the dry aggregate that is absorbed by the aggregate without altering the aggregate's bulk density, and which does not contribute towards inter-particle adhesion. The test is used to assess the suitability of aggregate for use in asphalt. High bitumen absorption values indicate aggregates that require higher binder contents to achieve the same adhesion properties relative to an aggregate with low absorption values.

The test is done by weighing a sample of oven-dried loose mix submerged in water in a flask at 25 °C. Suction is applied to the flask to reduce the residual pressure to a prescribed vacuum for a fixed period, after which the vacuum is gradually released. The volume of the mix is determined by the mass in air and water, and used to calculate the density.



Rice Density

The "Maximum Voidless Density" is known as the Rice Method, and consequently the density as the Rice density.

(vii) Soluble Binder Content and Particle Size Analysis (SANS 3001–AS20)

This method is used to quantitatively determine the binder content and particle size analysis of an asphalt mix for quality control, acceptance control and the evaluation of mix properties. Polymer modified asphalts need to have additional time for dissolving to ensure all the material is broken down, as well as extended washing regimes.

The test method involves extracting the binder from the mix with an organic solvent. As part of the procedure, the moisture content of the mix is determined. The binder content is calculated as the difference of the mass of the original asphalt and that of the extracted aggregate, moisture content and mineral matter in the extract. It is therefore regarded as an indirect method. The bitumen content is expressed as a percentage by mass of the moisture-free mix.



Soluble Binder Content and Particle Size Study

This test, SANS 3001–AS20, is not suitable for mixes with bitumen-rubber. Refer to SABITA Manual 19 for alternative options.

Polymer modified asphalts need to have additional time for dissolving and extended washing regimes to ensure all the material is broken down.

(viii) Immersion Index (TMH1 C5)

The immersion index is determined by soaking Marshall briquettes for 24 hours at 60 °C and expressing the Marshall stabilities obtained as a percentage of the mix's original Marshall stability. The test is used to assess the moisture sensitivity of asphalt mixes. Relatively low immersion index values indicate that the asphalt mix is sensitive to moisture. This test has largely been replaced by the Modified Lottman test.

(ix) Asphalt Content of Hot Mix Asphalt by Ignition Method (SANS-AS21)

This method is used for the quantitative determination of the bitumen content of hot mix asphalt samples for quality control, acceptance control and the evaluation of mix properties. This test method does not use toxic organic solvents and therefore has a significant health and safety advantage. Aggregate obtained by this test method may be used for particle size analysis.

To do the test, the binder in the asphalt mix is ignited in a furnace. The binder content is calculated as the difference of the mass of the residual aggregate and the moisture content. The binder content is expressed as a percentage by mass of the moisture-free mix.

The method provides for furnaces equipped with an internal, automated weighing system or furnaces without such a weighing system.

This method will soon be published by SANS.

(x) Gyratory Compaction (ASTM D6925-09)

This test covers the compaction of a cylindrical specimen of asphalt in a Superpave Gyratory Compactor. In this test, the relative density of the asphalt may be determined at any point in the compaction process. The compacted specimens are suitable for volumetric as well as physical property testing.

(xi) Hamburg Wheel-Tracking Device (HWTB) (Tex-24-F)

This test measures the susceptibility of asphalt mixes to both rutting and stripping. It can be applied to both laboratory prepared specimens or field cores. The test is employed to design asphalt mixes and to assess the properties of laid asphalt.

The HWTB tracks a loaded steel wheel back and forth on a HMA sample compacted to 7% air voids. Most commonly, the 47 mm wide wheel is tracked across a sample submerged in a water bath for 20 000 cycles (or until 20 mm of deformation occurs) using a 705 N load. The equipment is shown in Figure 31.



Figure 31. Hamburg Wheel-Tracking Device

Rut depth is measured continuously with a series of LVDTs on the sample. The temperature of the water bath can be set from 25 to 70 °C. The most common test temperature is 50 °C, although 40 °C has been used when testing certain base mixes.

(xii) Indirect Tensile Strength (ITS) Test (ASTM D6931-07)

This test is commonly used to evaluate the cohesive strength of asphalt mixes. The values of ITS may be used to estimate the potential for rutting or cracking in asphalt at low to medium temperatures. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both moisture-conditioned and unconditioned specimens, as described in the next test, Moisture Sensitivity Test (Modified Lottman).

In the test, a cylindrical asphalt specimen is loaded on the diametral axis at a fixed rate until a significant loss in applied load is noted. The peak load is used to calculate the ITS.

(xiii) Moisture Sensitivity (Modified Lottman) Test (AASHTO T283)

This test method is used in conjunction with mix design to determine the potential for moisture damage, to determine whether or not an anti-stripping additive is effective, and to determine what dosage of an additive is needed to maximize its effectiveness.

In this test, the ITS test (see above) is carried out on six cylindrical samples, compacted to within a specified void content range and partially saturated with water. Three samples are “conditioned” by freezing them for at least 15 hours and subsequently immersing them for 24 hours in a water bath set at 60 °C. The ratio of the ITS values of the conditioned and unconditioned samples, termed the tensile strength ratio (TSR), is used to assess the susceptibility to moisture damage.

(xiv) Dynamic Creep (CSIR RMT 004)

In the dynamic creep test, a cylindrical test specimen is subjected to repeated dynamic loads in the axial direction. The accumulated permanent deformation is monitored as a function of the number of load repetitions. In South Africa, a square wave load shape with a 1 second duration and 1 second rest period are typically used. The applied load is typically 100 kPa and the test temperature is 40°C.

The permanent strain that develops during the first 30 load applications is subtracted from the total permanent deformation after 3600 cycles. The dynamic creep test can be performed on compacted briquettes or field cores.

It should be noted that in recent years research work has raised some doubts concerning the ability of the dynamic creep test to properly and consistently evaluate the rutting potential of different mix types. The test is generally regarded as being inappropriate for evaluating mixes that rely on stone-to-stone contact to develop rutting resistance. For these reasons, the use of the dynamic creep modulus as an acceptance criterion is not recommended for mixes other than densely graded sand-skeleton mixes manufactured with unmodified binders.



Dynamic Creep

The dynamic creep test is generally regarded as being inappropriate for evaluating mixes that rely on stone-to-stone contact to develop rutting resistance. For these reasons, the use of the dynamic creep modulus as an acceptance criterion is not recommended for mixes other than densely graded sand-skeleton mixes manufactured with unmodified binders.

(xv) Air Permeability (TRH8 Appendix C)

This test method is used to determine the air permeability of compacted asphalt. It is carried out on either a laboratory compacted specimen, as part of the mix design procedure, or on a sample cored from the road to check the permeability of the in situ asphalt layer. The air permeability gives a good indication of the interconnection of the air voids in the asphalt. In the test, the asphalt specimen is positioned in a metal cylinder with the vertical walls of the specimen sealed by a rubber membrane. Air is evacuated so as to cause a pressure differential between the upper and lower surfaces of the specimen and the air permeability is measured using the rate of airflow through the sample.

(xvi) MMLS for Permanent Deformation and Moisture Damage (DPG1)

The permanent deformation performance and susceptibility to moisture damage of bituminous road pavement mixtures is evaluated using simulated traffic loading with the 3rd scale model Mobile Load Simulator (MMLS), shown in Figure 32, under controlled environmental conditions. This method is applicable to asphalt mixes containing penetration grade bitumen or modified binders used in surfacings or base layers.

The test uses a MMLS3 machine which is equipped with four axles with 300 mm diameter inflatable pneumatic wheels, circulating in a vertical closed loop. This configuration enables 7200 load repetitions per hour to be applied to the test bed, which can consist of laboratory prepared briquettes or core samples taken from the road, as well as on laboratory prepared slabs or on existing pavements in the field. At predetermined intervals, the trafficking is stopped and cross-sectional profiles are measured to determine the depth of rutting. The testing can be carried out at controlled temperatures. The test bed can be sprayed with water so that the mix's susceptibility to stripping can be evaluated.

This test will be republished as SANS 3001-PD1.

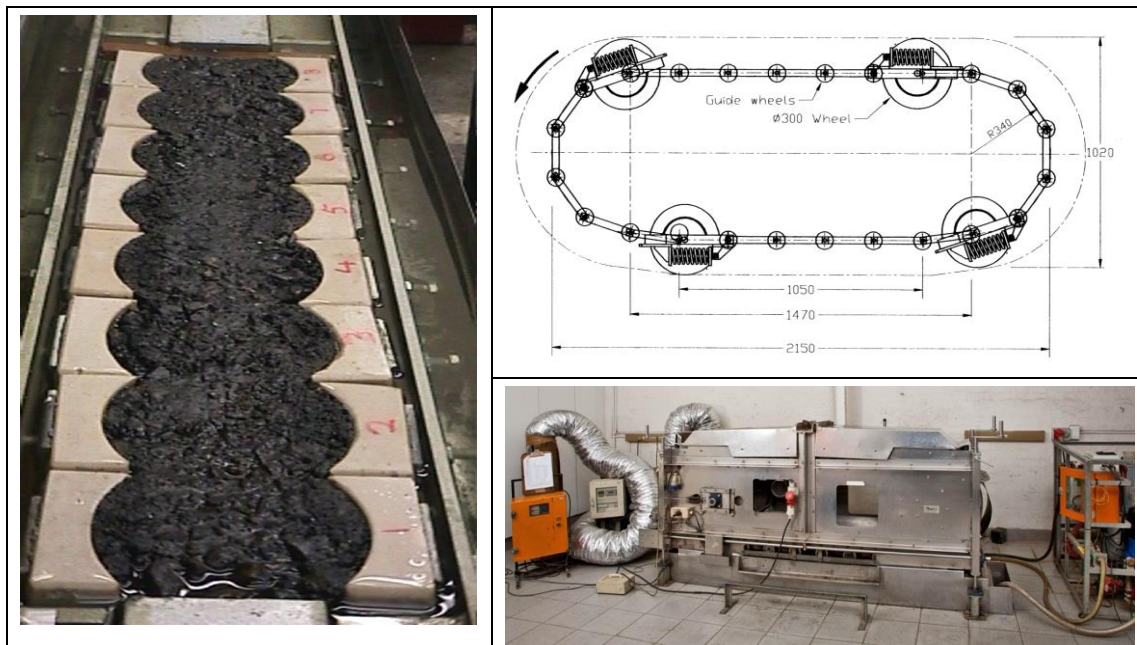


Figure 32. MMLS3

(xvii) Moisture Content in Asphalt (SANS 3001–AS23)

This test is used to determine the moisture content of freshly mixed asphalt. The moisture content of the asphalt may be determined either by distillation using Dean and Stark apparatus, or by oven drying.

(xviii) Cantabro Abrasion Test (Standard Specifications)

The Cantabro abrasion test is used to determine the abrasion resistance of porous asphalt mixes, i.e., mixes with void contents of approximately 20%). The abrasion resistance values are used to establish the optimum binder content of porous asphalt mixes.

To perform this test, Marshall briquettes of the mix are prepared with varying binder contents. A briquette is weighed and then placed in the drum of a Los Angeles Testing Machine. The drum is rotated for 300 revolutions with the briquette inside, causing it to impact with the walls of the drum. The briquette is removed, weighed again, and loss in mass and percentage abrasion is determined. These tests are carried out in triplicate at each binder content, and the results are compared against standard maximum abrasion loss values.

4.2.6 Field Control Tests on Asphalt

As opposed to laboratory tests carried out for the purposes of design and quality control there are some field tests that measure performance of the constructed asphalt. For example, the porosity of continuously graded hot mix asphalt is a critical factor in the durability of the road surface. Other factors measured are the ride quality, skid resistance and performance under load. Coring of asphalt is also done to check the compaction and to obtain field specimens for laboratory testing.

(i) Coring of Hot Mix Asphalt

Compaction of hot mix asphalt is routinely determined on core specimens. The following should be noted when carrying out asphalt coring:

- Coring of newly paved asphalt should only be undertaken once the **asphalt layer has fully cooled to ambient temperatures**. Coring while the asphalt is still warm could result in deformation of the cores, affecting the compaction results.
- Coring should be carried out when the **ambient temperature is low**, such as in the early morning; this procedure should be avoided during the heat of the day.



Additional Info on HMA Tests

Useful information on various tests carried out on hot mix asphalt is included in "Interim Guidelines for the Design of Hot Mix Asphalt in South Africa" (HMA, 2001).

- **Adequate cooling water should be provided**, otherwise there is a risk that the binder will heat up during the coring operation, smearing the core's periphery and affecting the compaction results.
- In cases where the **asphalt layer is less than 30 mm thick**, the cores extracted from the layer are likely to be too thin for accurate testing. A method type specification should preferably be used for compaction of thin asphalt layers, where the type and mass of the compaction equipment, as well as the number of roller passes is specified.

Compaction is determined by either:

- Comparing the bulk density of the core with the **Marshall density** of the same mix, or
- Comparing the bulk density of the core with its **maximum voidless density**

The compaction of hot mix asphalt layers may also be assessed using a nuclear gauge. Nuclear devices, popularly known as "thin layer gauges" have been developed especially for this purpose. Generally the guidelines given in Section 2.7.1 of this chapter to determine the compaction of soils and gravels using the nuclear method should be followed.

The use of nuclear gauges offers advantages in that the test does not damage the asphalt layer as does a core sample. Also the test can be carried out much more rapidly than core sampling and testing.

The nuclear method does however have disadvantages in that the results are affected by the binder content as well as the temperature of the asphalt layer. While the nuclear method is useful as a process control tool to monitor compaction versus roller passes, the results of compaction tests on the hot mat behind the roller are unlikely to be a sufficient reliability to use for acceptance purposes.

Some roller manufacturers offer compaction monitoring systems on their vibratory rollers that provide useful information on the degree to which the layer is compacted. Here again, the results are used more as an aid to process control rather than for final acceptance of compaction.

(ii) Permeability of a Bituminous Surface, Marvil Test (SANS 3001-BT12)

The test is carried out by placing a graduated open-ended cylinder (permeameter) on the asphalt surface and sealing the contact between the two with grease or other suitable material. The cylinder is kept filled with water for five minutes prior to the test.

The test is carried out by recording the rate of fall of the water level for a set volume of water or a three minute interval. This test provides a very visual demonstration of high permeability, usually where the voids in continuously graded asphalt are above 8 %, the water level falls almost faster than water can be added to the cylinder.

(iii) Skid Resistance

A number of tests to measure skid resistance have been used in South Africa of which the Scrim and Griptest are the most common. These tests are discussed in Chapter 6: 7.3.3. The pendulum test can also be used for localised assessment of the surface friction.

(iv) Riding Quality

Riding quality is normally measured using response-type vehicle-mounted equipment such as Linear Displacement Integrators (LDI), Bump Integrators or high speed profilometers making use of laser sensors. These determine the roughness of the road by measuring movement induced in the vehicle body through irregularities in the road, which is calibrated to known roughness conditions, usually determined by precise levelling. These results can be provided in a number of ways, for example, Quarter-car Index and International Roughness Index (IRI). Roughness measurements are discussed in Chapter 6: 7.3.1.

Other simpler but slower methods, which are better suited to short sections of road, include the rolling straight edge and California Profilometer.

4.3 Tests on Cold Mix Asphalt

Tests on cold mix asphalt involve tests of the component materials and of the mix.

4.3.1 Aggregates

The tests required on the aggregates used in cold mix asphalt are the same as those used in hot mix asphalt, and are covered in Table 8 and Section 4.2.2.

4.3.2 Filler

The tests required for filler are the same as those used in hot mix asphalt and are given in Table 8 and Section 4.2.3.

4.3.3 Binder

Two different types of binders are normally used in cold mix asphalt:

- **Cutback bitumen:** MC-800 or MC-3 000 complying with SANS 4001–BT2
- **Bitumen emulsion:** anionic premix grade or cationic premix grade
 - **Anionic** emulsions: SANS 4001–BT3
 - **Cationic** emulsions: SANS 4001–BT4

The testing of cutback bitumen and bitumen emulsion used in the manufacture of cold mix asphalt should be carried out in accordance with the test methods given in Sections 4.1.2 and 4.1.3, respectively.

Details of the test methods used to determine the properties required in these specifications are given in Table 7 and Section 4.1.3.

4.3.4 Mix Tests

Cold mix asphalt is also supplied using propriety ingredients. In this case, the suppliers' recommendations regarding testing requirements should be followed.

4.4 Tests on Surfacing Seals

Surfacing seals are used to provide a safe, dust-free, waterproof cover to the underlying pavement. They provide adequate skid resistance and protect the underlying layer from the destructive forces of traffic and the environment. The different types of seals are described in detail in Chapter 2: 2.3.1 and Chapter 9: 11. Surfacing seals can be conveniently divided into:

- **Spray seals:** alternating applications of stone chips and bituminous binders.
- **Slurries and micro-surfacings:** one or more applications of cold mixtures of emulsified bitumen, graded aggregate and cement or lime.

Testing on surfacing seals is carried out at two stages, prior to construction and during construction. Investigation of the aggregate **prior to construction** is to determine the basic properties in terms of:

- Hardness
- Resistance to polishing
- Durability
- Binder/aggregate adhesion
- Sand equivalent in case of sand seals and slurry seals
- Immersion index in case of slurry seals
- Plasticity in case of slurry seals

During the construction phase, for purposes of design and quality assurance, the following properties are tested:

- Design
 - Average least dimension (ALD)
 - Flakiness
 - Methylene blue test in case of micro-surfacing, to determine whether the clay content of the fines contains deleterious swelling clay minerals, such as



Seals

A good reference for seals is **TRH3: Design and Construction of Surfacing Seals (2007)**.

In **SAPEM**, seals are discussed in:

- Chapter 2, **Pavement Composition and Behaviour**, Section 2.3.1.2
- Chapter 4, **Standards**, Section 4.4
- Chapter 9, **Materials Utilisation and Design**, Section 11
- Chapter 12, **Construction Equipment and Method Guidelines**, Section 3.10 and 4.2
- Chapter 13, **Quality Management**, Section 7
- Chapter 14, **Post-Construction**, Section 4.1.1

- smectites, which could adversely affect the quality of the mix. Bulking due to moisture in case of slurry seals
- Wet Track Abrasion test recommended for slurries (Sabita Manual 28, 2011)
- Voids filled with binder recommended for slurries (Sabita Manual 28)
- Quality assurance
 - ALD when specified
 - Grading
 - Flakiness
 - Binder properties

4.4.1 Spray Seals

Testing of spray seals involves testing the component materials, i.e., the aggregate and binder.

4.4.1.1 Aggregates

Testing requirements for aggregates used in spray seals are covered in Table 9.

Except for the Average Least Dimension test (ALD), all the tests required on aggregates used in surfacing seals are described in previous sections.

Table 9. Test Requirements for Aggregates Used in Surfacing Seals

Application	Test/Property	Test Method ¹	Chapter Reference
Spray seals: Surfacing seal chips	Grading	SANS 3001-AG1	2.3
	Flakiness	SANS 3001-AG4	3.2.2
	ACV and 10% FACT	SANS 3001-AG10	3.2.5
	Polished stone value (PSV)	SABS 5848 (SANS 3001-AG11)	4.2.2(i)
	Average least dimension (ALD)	SANS 3001-AG2, AG3	4.4.1.1
Slurries and micro-surfacings: Crusher dust, sand	Grading	SANS 3001-AG1	2.3
	ACV	SANS 3001-AG10	3.2.5
	Sand equivalent	SANS 3001-AG5	4.2.2(ii)
	Immersion Index	TMH1 C5	4.2.5(viii)
	Plasticity (Atterberg limits)	SANS 3001-GR10	2.5
	Methylene blue test	SANS 1243	4.2.3(iii)

Notes

1. SANS test method in brackets will be the new SANS 3001 number when published.

(i) Average Least Dimension (ALD) (SANS 3001-AG3)

The average least dimension test is carried out on chips used in surfacing seals using two test methods:

- **SANS 3001-AG2**, the direct method. This requires each chip in the sample to be physically measured using a dial gauge.
- **SANS 3001-AG3**, is a computational method, based on the grading results.

The ALD results are used in the design of surfacing seals as well as to control the quality of crushed aggregates.

4.4.1.2 Binders

Several types of binders are used in spray seals:

- Penetration grade bitumen
- Modified binders, including homogenous and non-homogenous binders
- Bitumen emulsion
- Modified bitumen emulsion

The test methods are discussed in Section 4.1 and are listed in Table 7.

4.4.2 Slurries and Microsurfacing

Bituminous slurries and micro-surfacings basically comprise a mixture of fine aggregates, emulsified bituminous binder and a filler. The gradings of micro-surfacing mixes are usually coarser than those of slurries and they normally include a modified bitumen emulsion binder. Testing again involves testing the aggregate, binder and filler.

4.4.2.1 Aggregates

Testing requirements for aggregates used in slurries and micro-surfacings are covered in Table 9, Section 4.4.1.1.

4.4.2.2 Binders

The range of tests carried out on binders used in slurries and micro-surfacings is covered in Section 4.1, with the test methods being listed in Table 7.

4.4.2.3 Fillers

The tests required for the filler are the same as those used in hot mix asphalt and are given in Table 8, Section 4.2.3.

The Standard Specifications require an Immersion Index test on briquettes made with the slurry aggregate and 70/100 pen bitumen in accordance with Method C5 of TMH1.

Suppliers of propriety micro-surfacings and quick-set slurries should provide testing requirements applicable to their products.

4.4.3 Tests for the Design of Surfacing Seals

The selection and design of surfacing seals is covered in Chapter 9: 11. This section includes tests carried out on the existing road surface, such as ball penetration (SANS 3001-BT10) and texture depth (SANS 3001-BT11). The quality of the aggregates used in spray seals, such as their grading, average least dimension and shape (flakiness index), has a significant influence on the design. In the case of slurries, particularly quick-set slurries and micro-surfacings, the quality of the crusher and natural sand used in the mixes plays a major role.

4.4.4 Tests for Quality Assurance

In addition to tests mentioned under Sections 4.4.1 and 4.4.2, control tests and measurements including binder application, aggregate spread rates and binder content (slurries) are covered in Chapter 13, Section 7.

4.5 Tests on Primes, Precoating Fluids and Tack Coats

The majority of the tests required for primes, precoating fluids and tack coats is covered in Section 4.1, Testing of Bituminous Binders.

4.5.1 Primes

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

- MC-30 or MC-70 cutback bitumen grades: SANS 4001-BT2
- Inverted bitumen emulsion: SANS 4001-BT5

Should primes be used that do not comply with SANS specifications, typically proprietary products, the supplier should provide specifications to test the product for compliance. These materials, when tested in accordance with the test methods given in the Distillation Test in Section 4.1.6(ii), should comply with:

- Minimum residue from **distillation** of 50% of the total volume
- Penetration at 25 °C of the **residue** should be between 90 and 180 dmm



Eco-primes

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

Table 10. Test Requirements for Bituminous-Based Precoating Fluids

Property	Test Method	Chapter Reference
Saybolt Furol viscosity @ 50 °C, SF	ASTM D 244	Section 4.1.3(iii)
Distillation to 190 °C, 225 °C, 260 °C, 316 °C, 360 °C, v/v% ¹	ASTM D 402	Section 4.1.2(ii)
Residue from distillation to 360 °C, v/v%	ASTM D402	Section 4.1.2(ii)
Dynamic viscosity @ 25 °C of residue distilled to 360 °C (cps)	ASTM D 4402	Section 4.1.1(iii)
Stripping number ²	TMH1 B11 (Riedel & Weber)	Section 4.1.6(iii)

Notes:

1. v/v% = volume/volume expressed as a percent
2. 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 with the aggregate with and without precoating.

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 tests for bituminous-based precoating fluids are listed in Table 10.

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. In certain instances, a tack coat may be needed before applying a microsurfacing on an existing bituminous surfacing.

Tack coats consist of anionic or cationic stable grade bitumen emulsion diluted 1:1 with water. The testing of bitumen emulsions is described in Sections 4.1.3 and 4.1.5.

Details of typical application rates are given in Chapter 9: 7.3.4.

4.6 Tests on Bitumen Stabilized Materials (BSMs)

Bitumen stabilized materials are materials treated with foamed bitumen or bitumen emulsion. The materials are typically used for base layers and occasionally subbases. In TG2, BSMs are divided into three classes, BSM 1, 2 and 3, depending on the quality of the parent material design traffic and its position in the pavement, as follows:

- **BSM1:** This material has a high shear strength, and is typically used as a base layer for design traffic applications of more than 6 million standard axles (MESA). For this class of material, the source material is typically a well graded crushed stone or reclaimed asphalt.
- **BSM2:** This material has a moderately high shear strength, and would typically be used as a base layer for design traffic applications of less than 6 MESA. For this class of material, the source material is typically a graded natural gravel or reclaimed asphalt.
- **BSM3:** This material is typically a soil-gravel and/or sand, stabilized with higher bitumen contents. As a base layer, the material is only suitable for design traffic applications of less than 1 MESA.

The requirements for the three classes are based on the level of mix design being carried out. TG2 suggests three levels of mix design.

The foaming properties of foamed bitumen are tested using SANS 3001-BSM1.

4.6.1 Level 1 Mix Design

The Indirect Tensile Strength (ITS) test, which is a measure of tensile strength and flexibility of the material. In this test, cylindrical specimens, prepared at both equilibrium and soaked moisture conditions, are loaded on their diametral axes at a fixed rate until a significant loss in applied load is noted. The peak load is used to calculate the ITS of the specimens. The test is shown in Figure 33.



BSM Tests

This chapter outlines the most important test methods used for BSMs, while all material properties and test methods are referenced or described in detail in TG2.



Figure 33. Indirect Tensile Test (ITS)



ITS Tests for BSMs

- **ITS_{dry}**: 100 mm specimens dried in the oven
- **ITS_{wet}**: ITS_{dry} specimens soaked for 24 hours
- **ITS_{equil}**: 150 mm specimens subjected to specific curing procedure
- **ITS_{soaked}**: ITS_{equil} soaked for 24 hours

For Level 1 Mix design, the test is carried out on 100 mm diameter specimens to:

- Indicate the **optimal bitumen content** using ITS_{dry}, ITS_{wet} and TSR (ratio of ITS_{wet} to ITS_{dry}).
- Select the **active filler** type and content using ITS_{wet} and TSR.

4.6.2 Level 2 Mix Design

This level of mix design is carried out on 150 mm diameter ITS specimens to finalise the bitumen content:

- Tensile strength at equilibrium moisture content using ITS_{equil}.
- Tensile strength after moisture exposure using ITS_{soaked}.

4.6.3 Level 3 Mix Design

This level of mix design is carried out in place of Level 2 design for high levels of design traffic. It employs a simple triaxial test to assess the shear strength of the BSM and its resistance to the adverse effects of moisture using the MIST apparatus described in TG2.

(i) Triaxial Test

The triaxial test, shown in Figure 34 is used to determine shear properties, and the resilient modulus and permanent deformation of a material. The test is done using cylindrical specimens in two modes:

- **Monotonic testing:** A confining pressure is applied to the specimen, and a static load is applied vertically. Typical results are shown in Figure 35. By using a range of confining pressures, the shear properties of a material can be determined using the Mohr Coulomb representation, as shown in Figure 36. The tangent to the Mohr Coulomb circles is known as the failure envelope as stress states above this line cannot exist. The slope of this line is known as the angle of internal friction ϕ (in degrees) and the y-intercept is known as the cohesion C (in kPa). These are known as the shear parameters.
- **Dynamic testing:** A confining pressure is applied and a vertical load is repeatedly applied, typically for 0.1 seconds with a 0.1 second rest period. Varying the confining and vertical pressures allows the determination of the resilient modulus.

The resilient modulus, generically known as the stiffness, of a material used in a pavement layer provides a good indication of the load spreading capacity of the layer. The slope of the unloading cycle in a dynamic test is the Resilient Modulus. In reality, wheel loads on a layer are dynamic with relatively low strain levels. So, dynamic testing is needed in the laboratory to simulate field behaviour.



Figure 34. Triaxial Test

Triaxial testing is not currently widely used. However, it is likely to become a standard test for granular and stabilized materials. A testing protocol for the triaxial test is being standardised as part of the revision of the South African Mechanistic Design Method. A provisional protocol is given in Mgangira et al (2011). Figure 34 shows a typical triaxial test, in which specimens 150 mm in diameter and 300 mm in height are tested.

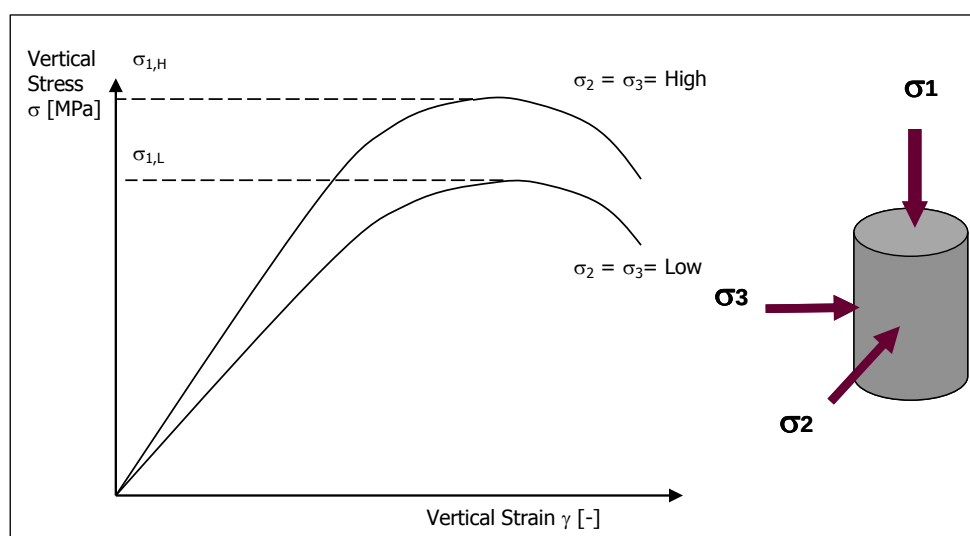


Figure 35. Monotonic Triaxial Tests on Granular Material

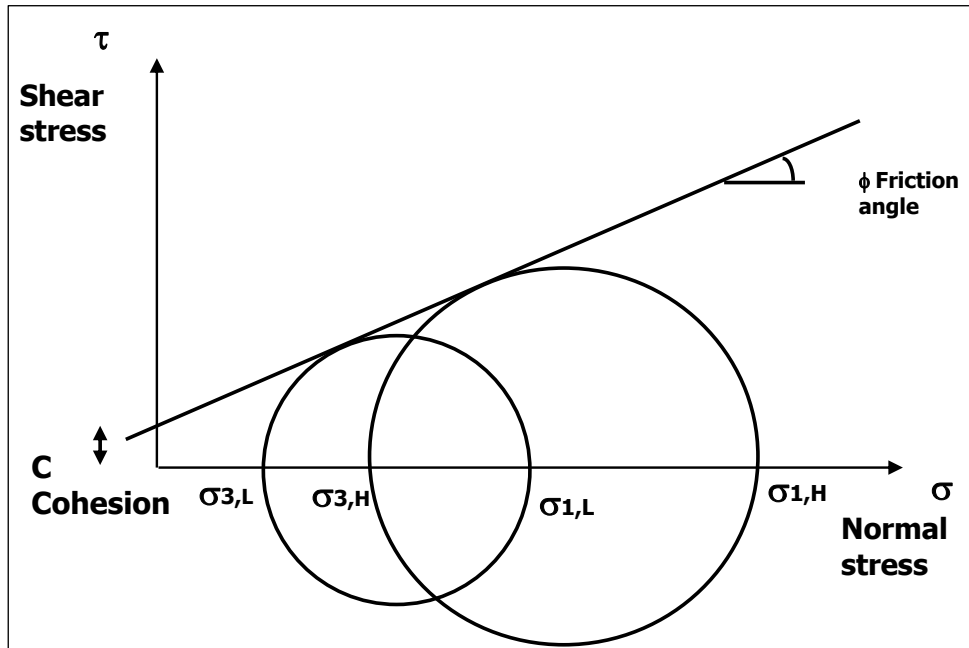


Figure 36. Mohr Coulomb Plots of Monotonic Triaxial Test Results

5. TESTS ON CEMENTITIOUS MATERIALS

This section covers the testing of a wide range of cementitious materials, including:

- **Concrete** after it has been manufactured, reinforcing, joint sealants and the components that make up concrete.
- Materials used in the manufacture of **concrete blocks** used in segmental block pavements, as well as jointing and bedding sand.
- **Stabilization** using cementitious materials.

The main aim is to guide the reader to select appropriate tests to ensure that the materials comply with the requirements of the relevant specifications before, during and after construction.

5.1 Testing of Concrete and its Components

The main components of concrete include crushed stone, sand, cement and water. Various extenders and admixtures are used to enhance the costs and 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 increase the strength of the concrete and to control the crack pattern in continuously reinforced concrete pavements. Joint sealants are used to seal formed joints in concrete pavements. This section covers tests on all these materials as well as tests on fresh and hardened concrete.

5.1.1 Tests on Aggregates used in Concrete

As listed in Table 11, a large number of tests are carried out to check the quality of aggregates used in the manufacture of concrete. Note that several of these tests are the same as those used in the manufacture of other crushed stone products covered in Section 3. The appropriate application as well as the information that is gained from these tests is given in Section 5.2 of C & CI's "Guideline to the Common Properties of Concrete" (C & CI, 2009), and is presented in tabular form in Appendix A of that guideline. Because the properties and tests for concretes are adequately discussed in the C & CI guideline, they are not all discussed in detail in this manual.

Examples of insight regarding the properties of concrete that can be gained from tests on the aggregates are given in Table 12.

Further information on the testing of concrete aggregates is given in Chapter 3, Aggregates for Concrete in the 9th edition of Fulton's "Concrete Technology" (2009). More specialised testing requirements for aggregates used in concrete for the construction of pavements are contained in Section 6 of C & CI's "Concrete Road Construction" (C&CI, 2009).

5.1.2 Tests on Cement

The South African standard for "Common cements" is SANS 50197-1 Cement. Part 1: Composition, specifications and conformity criteria for common cements, and this is supported by SANS 50197-2-2000 Cement. Part 2: Conformity evaluation.

The standard specifies the composition of cements according to the proportions of its constituents, which typically includes Portland cement clinker, extenders and fillers. Strength requirements are determined in accordance with SANS 50196-1 Methods of Testing Cement. Part 1: Determination of Strength. The other tests carried out on cement are shown in Table 13. These specialised tests are generally done by the cement manufacturer, and not by the road building industry. The tests are therefore not discussed further in this manual.



Concrete Pavements

The different types of concrete pavements are shown in

- Chapter 2, **Pavement Composition and Behaviour**, Section 2.4
- Chapter 9, **Materials Utilisation and Design**, Section 12.2.2.

Standards for concrete pavements are included in Chapter 4, Section 5.1.

The design of concrete pavements is in:

- Chapter 9: **Materials Utilisation**, Section 12
- Chapter 10: **Pavement Design**, Section 8

Construction and quality management of concrete pavements are discussed in:

- Chapter 12, **Construction Equipment and Method Guidelines**, Section 2.9, 3.12 and 4.7
- Chapter 13, **Quality Management**, Section 8

Distress in concrete pavements is discussed, and illustrated, in:

- Chapter 14: **Post-Construction**, Section 4.2

Table 11. Tests on Aggregates for Concrete

Property	Test Method	Section Reference
Sampling of aggregates	SANS 195	
Preparation of test samples of aggregates	SANS 197	
Particle size analysis of aggregates by sieving	SANS 3001-AG1	2.3
Particle size distribution of material of diameter smaller than 0.075 mm in fine aggregate (hydrometer method)	SANS 6241	2.3(iii)
Particles of diameter not exceeding 20 µm and not exceeding 5 µm and smaller, respectively, in fine aggregate (pipette method)	SANS 6244	
Computation of soil-mortar percentages, coarse sand ratio, grading modulus and fineness modulus	SANS 3001-PR5	2.3
Determination of the flakiness index of coarse aggregates	SANS 3001-AG4	3.2.2
Low density materials content of aggregates	SANS 5837	
Soundness of aggregates (magnesium sulphate method)	SANS 5839	
Aggregate crushing value and FACT value (10% fines aggregate crushing value) of coarse aggregates	SANS 3001-AG10	3.2.5
Water absorption of aggregates	SANS 5843	
Particle and relative densities of aggregates	SANS 5844	
Bulk densities and voids content of aggregates	SANS 5845	
Polished stone value of aggregates	SANS 5848	4.2.2(i)
Free water content of aggregates	SANS 5855	
Determination of the dry bulk density (BD), apparent density (AD) and water absorption of aggregate retained on the 5 mm sieve	SANS 3001-AG20 & AG21	3.2.9
Determination of the dry bulk density (BD), apparent density (AD) and water absorption of material passing the 5 mm sieve	SANS 3001-AG20 & AG21	3.2.9
Estimation of the effect of fine aggregate on the water requirement of concrete	SANS 5835	
Effect of fine and coarse aggregate on the shrinkage and expansion of cement: aggregate mixes (mortar prism method)	SANS 5836	
Sand equivalent value of fine aggregates	SANS 5838	4.2.2(ii)
Shell content of fine aggregates	SANS 5840	
Bulking of fine aggregates	SANS 5856	
Chloride content of aggregates	SANS 202	
Presence of chlorides in aggregates	SANS 5831	
Organic impurities in fine aggregates (limit test)	SANS 5832	
Detection of sugar in fine aggregates	SANS 5833	
Soluble deleterious impurities in fine aggregates (limit test)	SANS 5834	
Total water-soluble salts content of fines in aggregates	SANS 5849	
Sulphates content of fines in aggregates Part 1: Water soluble sulphates in fines in aggregates	SANS 5850-1	
Sulphates content of fines in aggregates Part 2: Acid-soluble sulphates in fines in aggregates	SANS 5850-2	
Acid insolubility of aggregates	SANS 6242	
Deleterious clay content of the fines in aggregate (± adsorption indicator test)	SANS 6243	
Potential reactivity of aggregates with alkalis (accelerated mortar prism method)	SANS 6245	



Report the Test Method

When test results are reported, the test method used must be stated.

Table 12. Effect of Aggregate Properties on Concrete

Property	Method	Effect on Concrete
Sieve analysis, fines content and dust content of aggregates (fine aggregates)	SANS 3001-AG1 SANS 6241	- Concrete workability - Water requirement - Shrinkage - Durability - Slump - Compaction - Bleeding - Finish - Costs
Flakiness index of coarse aggregates	SANS 3001-AG4	- Concrete workability - Voids content - Water requirement
Determination of the Aggregate Crushing Value	SANS 3001-AG10	Compressive strength and abrasion resistance of concrete
Determination of the 10% Fines Aggregate Crushing Value (10% FACT)	SANS 3001-AG10	
Effect of fine and coarse aggregate on the shrinkage and expansion of cement:aggregate mixes (mortar prism method)	SANS 5836	Dimensional stability of concrete
The determination of organic impurities in sand for concrete	SANS 5832	- Short term retardation of concrete strength - Long term deleterious effect
Detection of sugar in fine aggregates	SANS 5833	
Soluble deleterious impurities in fine aggregates (limit test)	SANS 5834	

Table 13. Tests Carried out on Cement

Property	Test Method
Chemical analysis of cement	SANS 50196-2
Determination of setting times and soundness	SANS 50196-3
Quantitative determination of constituents	SANS 50196-4
Pozzolanicity test for pozzolanic cement	SANS 50196-5
Determination of fineness	SANS 50196-6
Methods of taking and preparing samples of cement	SANS 50196-7

5.1.3 Tests on Cement Extenders

SABS 1491 Parts 1, 2 and 3 contain the requirements for ground granulated blast furnace slag, fly ash and silica fume, respectively.

5.1.4 Tests on Water used in the Manufacture of Concrete

Fulton's devotes a chapter to "Mixing Water". In this chapter, extensive reference is made to BS EN 1008 "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". Test methods from BS EN 1008:2002 for the various determinations required are:

- Chloride, sulphate and alkali content
- pH
- Harmful contaminants, including sugar, phosphates, nitrates, lead and zinc
- Setting time
- Strength

Fulton's includes a map of South Africa, which illustrates various areas in the country where naturally occurring water can be expected to be suitable for use in concrete, while other areas are shown where the natural water could be problematic due to the likely presence of chlorides or alkalis and testing becomes mandatory. It should also be noted that water in rivers and streams in sugarcane growing areas could contain sugar,



Water in Sugarcane Areas

Water in rivers in sugarcane areas should be tested for the presence of sugar.

and tests for the presence of sugar should be undertaken in these cases. In Chapter 13: 8.1.4, Table 26 gives water requirements for different concrete applications.

5.1.5 Tests on Chemical Admixtures

Currently very little concrete is manufactured without the addition of chemical admixtures, which affects the properties of both fresh and hardened concrete. At present there is no South Africa specification covering the quality and performance of admixtures, and reliance is placed on the European EN 934 and American ASTM C494 specifications. In the case of air entraining admixtures, ASTM C260 is specified.

When the use of admixtures are considered as a means of enhancing specific properties of concrete, the literature supplied by the admixture supplier will provide general information on the use, characteristics, precautions and effect of the particular admixture. In most cases, and certainly if no previous experience has been gained with the particular admixture, as well as with the respective concrete components, laboratory mix design testing should be carried out to verify that the desired properties are obtained using the admixture. It is also essential to confirm that the required properties are achieved by carrying out site trials.

During the full-scale concrete manufacturing process, quality assurance should include tests to check that the admixture is the same as that tested and accepted previously, and that its quality is consistent. The following tests can be used:

- Specific gravity
- pH
- Viscosity
- Solids content
- Reflective index
- Infrared spectrophotometer measurements

These tests are done by the cement manufacturer, and not normally in the road building industry. Therefore, no additional details are provided.

Additional information on the use of chemical admixtures, with further details of testing, is available in Fulton's Chapter 5 as well as in Section 5.3 of C & CI's "Guideline to the Common Properties of Concrete".

5.1.6 Tests on Curing Compounds

Various methods to facilitate the curing of concrete are used, including the formwork itself, impervious sheeting, and keeping the concrete work damp using water sprays.

In some cases, and certainly for concrete road pavements, where a large area of concrete is exposed, a pigmented resin-based curing compound is used. The curing compound should be white pigmented and should not contain any water. Results of tests carried out on the curing compound should comply with ASTM C309, except that the water loss requirement should be substituted with the efficiency-index as determined in accordance with BS 7542.

Quality assurance should include specific gravity testing to check the consistency of the curing compound. Proper mixing of the curing compound must be carried out prior to these tests to ensure that the full product is tested.

5.1.7 Tests on Reinforcing Steel

The results of tests carried out on reinforcing steel should comply with SABS 920. Samples of each consignment of reinforcing steel are tested for compliance.

5.1.8 Tests on Concrete

The testing of concrete can be divided into two sections:

- Testing of **fresh concrete**
- Testing of **hardened concrete**

5.1.8.1 Tests on Fresh Concrete

Tests carried out on fresh concrete are shown in Table 14. Again, because many of these tests are discussed in C & CI's "Guideline to the Common Properties of Concrete" (2009), they are not all discussed in detail in this manual.



Fresh and Hardened Concrete

- **Fresh concrete** is the concrete that is still in a plastic or semi-plastic workable state.
- **Hardened concrete** is concrete that has gained sufficient strength to no longer be termed a semi-liquid or weak solid, i.e., it can no longer be worked or finished.

Table 14. Tests Carried out on Fresh Concrete

Description of Concrete Tests	Test Method ¹	Section Reference
Mixing fresh concrete in the laboratory	SANS 5861-1 (SANS 3001-CO1-1)	
Sampling of freshly mixed concrete	SANS 5861-2 (SANS 3001-CO1-2)	
Consistence of freshly mixed concrete: Slump test	SANS 5862-1 (SANS 3001-CO1-3)	5.1.8.1
Consistence of freshly mixed concrete: Vebe test	SANS 5862-3 (SANS 3001-CO1-4)	
Consistence of freshly mixed concrete: Compacting factor and compaction index	SANS 5862-4 (SANS 3001-CO1-5)	
Consistence of freshly mixed concrete: Flow test	SANS 5862-2 (SANS 3001-CO1-6)	
Density of compacted freshly mixed concrete	SANS 6250 (SANS 3001-CO1-7)	
Air content of freshly mixed concrete: Pressure method	SANS 6252 (SANS 3001-CO1-8)	
Dimensions , tolerances and uses of cast test specimens	SANS 5860 (SANS 3001-CO2-1)	
Making and curing of test specimens	SANS 5861-3 (SANS 3001-CO2-2)	
Consistence of freshly mixed concrete: Bleeding test	ASTM C232-92	5.1.8.1

Note

1. SANS test method in brackets will be the new SANS 3001 number when published.

(i) Slump Test

Probably the most frequently used test on fresh concrete is the slump test, illustrated in Figure 37. The test determines the ease with which concrete may be placed, compacted, and moulded. By tapping the metal base plate on which the test is conducted and observing the mode of collapse, the cohesiveness of the concrete and its tendency to segregate can be assessed. Other useful observations that can be made during this fairly straightforward test are the concrete's potential for bleeding, as well as how the surface will finish.

Slump tests are suitable for concrete with slumps of greater than 5 mm and less than 175 mm. The maximum stone size used in the concrete should not be larger than 40 mm. When the concrete slump is 10 mm or less and it contains maximum 40 mm stone size, the Vebe test is valid for measuring the workability of the concrete. The Vebe test is often applicable for mixes placed with slipform paving methods. The compaction factor test is also to assess the workability of concrete mixes, however this is rare.



Figure 37. Slump Test

(ii) Bleeding Test

Bleeding is a form of segregation in which some of the mixing water rises to the surface of the fresh concrete as the solid materials settle, resulting in a layer of clear or slightly green water.

Besides using the slump method mentioned above to assess the bleeding potential of the concrete, the rate and total bleeding capacity of the mix can be determined using ASTM C232-92. This test method entails drawing off the bleed water into a pipette from a compacted sample of the fresh concrete.

The measurement of the air content of concrete becomes important when air entraining admixtures are used, as may be done for road pavement mixes to improve workability. High air contents reduce concrete strengths, and air content tests are necessary to monitor this property using SANS 6252 (will be SANS 3001-CO1-8).

5.1.8.2 Tests on Hardened Concrete

Tests carried out on hardened concrete are listed in Table 15. Those tests not discussed in this manual are included in C & CI's "Guideline to the Common Properties of Concrete" (2009).

(i) Strength Testing

Compressive strength is the most commonly specified property of hardened concrete and is generally measured with the cube test. Methods for sampling, making, and curing and crushing to obtain the compressive strength of cube specimens are covered in Table 15. The crushing test is illustrated in Figure 38. The tensile splitting strength test (SANS 6253, will be SANS 3001-CO2-6) is used much less.

The **flexural** strength of hardened concrete (SANS 5864, will be SANS 3001-CO2-5) is however routinely used in the design and the quality assurance of concrete used in road pavements. Details of this testing procedure are given in C & CI's "Concrete Road Construction". The test is shown in Figure 39.



Figure 38. Compressive Strength Test



Figure 39. Flexural Beam Test

Table 15. Tests Carried out on Hardened Concrete

Description	Test Method ¹	Section Reference
Compressive strength of hardened concrete	SANS 5863 (SANS 3001-CO2-3)	5.1.8.2
Flexural strength of hardened concrete	SANS 5864 (SANS 3001-CO2-5)	5.1.8.2
Tensile splitting strength of hardened concrete	SANS 6253 (SANS 3001-CO2-6)	
Shrinkage Tests	SANS 6085 (SANS 3001-CO2-7)	5.1.8.2
Density of hardened concrete	SANS 6251 (SANS 3001-CO2-8)	
Drilling, preparation, and testing for compressive strength of cores taken from hardened concrete	SANS 5865 (SANS 3001-CO3-5)	
Interpretation of core testing	SANS 10100-2, Section 14.4.3	
Non-destructive tests • Rebound or Schmidt hammer • Ultrasonic testing • Pull out tests • Load tests	SANS 10100-2, Section 15.2.3	5.1.8.2
Alkali-silica reactivity	SANS 6245	5.1.8.2

Note

1. SANS test method in brackets will be the new SANS 3001 number when published.

(ii) Non-Destructive Tests on Hardened Concrete

The following non-destructive tests can be done on hardened concrete:

- **Rebound or Schmidt hammer testing.** A rebound or Schmidt hammer is a device that delivers a standard impact on a concrete surface and measures the rebound of the standard weight. The results of tests using this method are used to compare concrete of suspect strength with that of adequate strength. As the device does not give a direct readout of strength, the results should not be used to decide on the structural integrity of concrete, or in the settlement of disputes.
- **Ultrasonic testing.** Various devices are used to measure the speed of sonic impulses through concrete. The results are used to correlate the strength and density of concrete.
- **Pull out tests.** Pull out tests are carried out by casting devices into concrete and then pulling them out using hydraulic equipment. The force required to pull the device out of the concrete is used to assess the concrete strength.
- **Load tests.** This entails loading the concrete element with a dead load at 1.25 times its design live load and observing its deflections. The method is outlined in SANS 10100-2, Section 15.2.3.

(iii) Shrinkage Testing

Concrete shrinkage is covered in detail in Fulton's Concrete Technology, Chapter 4.5 under "Standards for hardened concrete". The test method used to determine the shrinkage of concrete, is carried out on specimens that are dried in an oven. This regime obviously does not simulate what happens in the field and the interpretation of the results is therefore questionable.



Shrinkage Tests

Shrinkage tests use specimens dried in an oven, which is not representative of field drying. The results are therefore questionable.

(iv) Alkali-Silica Reactivity

Although alkali-silica mainly concerns aggregate properties, mention is made of it again as the results are influenced by the dilution and effect of cement extenders, and the test is carried out on prisms of hardened concrete. The test method used to gauge the alkali-silica reactivity of aggregates is SANS 6245. The Standard Specifications also contain an accelerated test method for determining the potential alkali reactivity of aggregates.

5.2 Testing for Concrete Blocks and Paving Components

The segmental block paving system comprises the concrete blocks themselves, as well as bedding sand and jointing sand. The following documents provide additional information regarding testing requirements for concrete blocks and other materials used in the block paving system:

- SANS 1058, concrete paving blocks
- UTG 2
- Concrete Manufacturer's Association, "Concrete Block Paving" (CMA, 2009)
- Standard Specifications

Typical concrete blocks are shown in Figure 40.

The following sections list the tests required on concrete blocks and bedding and jointing sand, which are summarised in Table 16.



Figure 40. Concrete Blocks

Table 16. Tests Carried out on Concrete Blocks and Paving Components

Applicability	Description	Test Method	Chapter Reference
Concrete blocks	Strength tests: Tensile splitting test	SANS 1058	5.2.1
	Abrasion resistance		
	Water adsorption		
Bedding or jointing sand	Grading	SANS 3001–GR1	5.2.2
	Plasticity (presence of clay)	SANS 3001–GR10	

5.2.1 Tests on Concrete Blocks

Concrete blocks are manufactured to close tolerance and measurements are taken to check that they conform to dimensional specifications, which include length, width and thickness limits, as well as limits for length to thickness ratio.

The blocks are tested for strength using the tensile splitting test specified in SANS 1058.

The method for testing the abrasion resistance of concrete paving blocks is included in SANS 1058 and is carried out by mounting block specimens on a specially designed rotating drum containing steel ball bearings. The blocks are subjected to both impact and sliding abrasion by the ball bearings as the drum rotates.

A method for testing the water absorption of concrete blocks is also included in SANS 1058.

5.2.2 Tests on Bedding and Jointing Sand

Bedding and jointing sand have different grading specifications. No clay or silt is allowed in the bedding sand. The SANS 3001-GR1 (see Section 2.3) test method should be used to determine the grading of both bedding and jointing sand while SANS 3001-GR10 (see Section 2.5) is used to determine whether the bedding sand has any plasticity, which would indicate the presence of clay in the sand.

5.3 Testing of Cementitiously Stabilized Materials

Cementitiously stabilized materials consist essentially of crushed stone or natural gravels that has been treated with a cementitious stabilizing agent such as cement or hydrated lime, and used as a structural layer in a road pavement. In TRH14, the material classes for Cementitiously Stabilized Materials are the C-classes: C1, C2, C3 and C4.

Table 17 summarises methods used to test cementitiously stabilized materials, such as those stabilized with:

- Common cements
- Hydrated lime
- A combination of these products
 - Blends of lime or cement with fly ash
 - Blends of lime or cement with ground granulated blast furnace slag (GGBS)



Cementitious Stabilization

Various aspects of cementitious stabilization are discussed in:

- Chapter 4: **Standards**, Section 5.3
- Chapter 9: **Materials Utilisation and Design**, Section 6
- Chapter 10: **Pavement Design**, Section 7
- Chapter 12: **Construction Equipment and Method Guidelines**, Section 3.4 and 4.5
- Chapter 13: **Quality Management**, Section 4

Table 17. Tests for Cementitious Stabilizing Materials

Description	Test ¹	Chapter Reference
Tests Carried Out Before Construction		
Initial consumption of stabilizer	SANS 3001–GR57	5.3.1(i)
Maximum dry density and optimum moisture content of laboratory mixed cementitiously stabilized materials	SANS 3001–GR31	5.3.1(ii)
Preparation, compaction, and curing of specimens of laboratory mixed cementitiously stabilized materials	SANS 3001–GR50	5.3.1(iii)
Wet/dry brushing test	SANS 3001–GR55	5.3.1(v)
Acceleration carbonation test	Appendix A, Method A.1	5.3.1(vi)
CSIR erosion test	CSIR	5.3.1(vii)
Strength loss versus mixing time	Appendix A, Method A.2	5.3.1(viii)
Field Control Tests		
Degree of compaction	TMH 1 A10(a) and A10(b) SANS 300–NG1 to NG5	2.7 5.3.2(i)
Stabilizer content	TMH1 A15(d) (SANS 3001–GR58)	5.3.2(ii)
UCS (unconfined compressive strength)	SANS 3001–GR53	5.3.2(iii)
ITS (indirect tensile strength)	SANS 3001–GR54	5.3.2(iii)
Sampling and preparation of cored specimens of field compacted matured cementitiously stabilized material	SANS 3001–GR52	5.3.2(iv)
Atterberg limits ²	SANS 3001–GR10 or GR11	2.5
Grading ³	SANS 3001–GR1	2.3

Notes

1. SANS test method in brackets will be the new SANS 3001 number when published.
2. Atterberg limits done of material retained after UCS and ITS testing.
3. Grading done prior to compaction and cementation, otherwise the results are meaningless.

5.3.1 Tests Carried Out Before Construction

As is the case for gravels and aggregates, various tests are necessary during the design stage of cemented materials to ensure that the required standards described in Chapter 4 are achieved.

The first step is to classify the material to be treated in terms of the standard tests discussed under testing of gravels (Section 2). It is generally accepted that materials for treatment with lime or cement should be of at least G6 quality to ensure successful treatment. Once standard gravel tests have shown the material to be suitable, additional stabilization tests should be carried out.



Untreated Material Class

It is generally recommended that materials to be treated with lime or cement should be at least G6 quality.

These include tests to determine the type and quantity of stabilizer as well as tests to ensure that the treatment will be effective and long-lasting (durable).

As different materials react differently with various stabilizers, it is important to ensure that the stabilizer selected is the best and most cost-effective for any specific material and that it will be readily and economically available at the specific construction site.

A number of initial tests are carried out to ensure the materials suitability for stabilization. These are described in the following sections.



Suitability of Material for Stabilization

When the ICS is less than 3.5%, the material is likely to be suitable for stabilization.

(i) Initial Consumption of Stabilizer, ICS (SANS 3001–GR57)

The gravel ICS test should be carried out initially to determine the approximate content of stabilizer required. This method is titled "Determination of the cement or lime demand of cementitiously stabilized materials". Samples are prepared at varying stabilizer contents, usually 0%, 1%, 2%, 3%, 4% and 10%, and water is then added to form a paste. The pH of each sample is measured using a pH meter. The pH is plotted against the stabilizer content and the stabilizer content at which the pH reading is close to 12.4, and remains stable, is taken as the ICS of that material.

The interpretation of the test using the pH versus stabilizer content curve can be problematic as there is seldom a definite point at which the pH stabilizes. In particular, the selection of a suitable pH probe, calibration of the probe at a high pH value (preferably about 12), and the satisfactory condition of the probe (the high alkalinity and abrasion by the test specimen shorten the lives of the probes significantly), are critical to the test method.

If stabilization appears to be effective, feasible and economic, i.e., the ICS is not too high (not more than about 3.5%), proceed with further tests to establish the best stabilizer type and content to achieve the desired strength.



ICL vs ICS

The Initial Consumption of Lime (ICL) test is now the Initial Consumption of Stabilizer test, and includes the approximate content of both lime and cement required.

(ii) MDD and OMC of Stabilized Material (SANS 3100-GR31)

For strength testing and construction quality control, it is necessary to determine the maximum dry density and optimum moisture content of the material treated with the designed quantity of stabilizer. This testing must use the same stabilization product that is intended to be used during construction. See Section 2.6 for a discussion of the tests.

(iii) Preparation, Compaction, and Curing of Specimens of Laboratory Mixed Cementitiously Stabilized Materials (SANS 3001-GR50)

This test method describes the method for preparing and compacting specimens which are then cured before being tested for unconfined or indirect tensile strength. The test method caters for various curing methods.

(iv) Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) (SANS 3100-GR53 and SANS 3100-GR54)

Unconfined compressive strength (Figure 41) and indirect tensile strength testing (Figure 33) is carried out as part of the mix design procedure to establish an appropriate stabilizing agent, as well as for quality control purposes during construction. The strengths determined by these tests identify the expected C-class that the material will achieve with different stabilizer contents. Test programs involving more than one stabilizing agent require a significant amount of material and this must be remembered during the field investigation of borrow pits.

Because laboratory conditions often do not resemble field conditions (particularly ambient temperature and humidity), a shift between design and field construction results occurs. Different stabilizer types combined with



Differences in Density of Lime and Cement

The relative densities of lime and cement differ considerably, with averages of about 2.35 and 3.14, respectively and bulk densities of about 640 – 720 and 1520 kg/m³, respectively. This has a significant bearing on stabilization design and testing where laboratory investigations typically use mass for calculating stabilization quantities. In practice, the volume of 1 ton of cement is about 50% of that of 1 ton of lime, and this needs to be taken into account when working with these two materials in terms of spread rates on site, amount added during laboratory testing, etc.

different materials can exhibit very different strength versus time characteristics, especially those involving lime. At the design stage it is recommended that apart from comparisons between short term curing methods at least one set of long term test (90 days) should be considered.

Care should be observed with the ITS test when the test specimen contains large aggregate particles. These can often lead to "premature" failure of the specimen around such particles, producing a non-representative result. Such occurrences must be recorded in the test result report.

To speed up testing, the samples may be cured at a higher temperature for a shorter time than the standard of 7 days at 22 °C. Although the strength after 24 hours at 70 to 75 °C has been used as an estimate of the 7 day strength this is not necessarily valid for all material and stabilizer combinations. Accelerated curing tends to overestimate the 7 day strength in most cases. It is recommended that correlation tests be done using the stabilizer and material from the project if accelerated curing is to be used on a project.



Long-Term Curing

Short term curing cannot exactly represent long term field curing, therefore it is recommended that one set of long term (>90 days) cured specimens is tested.



Accelerated Curing

Accelerated curing typically overestimates the 7 day strength of stabilized materials.



Figure 41. Unconfined Compressive Strength Test



Figure 42. Wet/Dry Brushing Test (Mechanised Brushing)

(v) Wet/Dry Brushing Test (SANS 3001-GR55)

To determine that the quantity of stabilizer added is adequate to ensure the long-term durability of the stabilized materials, the wet/dry brushing test and the accelerated carbonation test should be carried out. In the more humid areas where chemical weathering (as opposed to mechanical weathering) is dominant, it is essential that the wet/dry brushing test is carried out.

The wet/dry brushing test, illustrated in Figure 42, is carried out by brushing specimens after each wet/dry cycle by hand. The test assesses the effect of wetting and drying on the surface of stabilized specimens. Coincidentally, it also indirectly takes into account the effect of carbonation of the specimen surface as some degree of carbonation occurs during the drying cycle.

Problems are sometimes encountered with the wet/dry brushing test when the materials being tested include large particles. The “plucking” of a single stone near the surface of the specimen during brushing can have a large impact on the results. Operators should be instructed to record (and photograph if possible) such cases so that the design engineer can assess the impact of this on the overall results.

The CSIR have developed a mechanised brushing system which eliminated possible variations in the pattern and force applied when using the manual brushing method. The test method for the mechanised test is currently under review and will be published as SANS 3001-GR56.

(vi) Accelerated Carbonation Test (Appendix A, Method A1)

To assess whether carbonation of the material will have a significant effect on the strength/durability of the stabilized material, the accelerated carbonation test should be carried out. This test involves subjecting a compacted specimen of the stabilized material to an environment of 100% carbon dioxide and assessing the effect on the strength of the material.

The accelerated carbonation test has been shown to indicate that if the residual strength of the material after carbonation exceeds the design strength, the effects of carbonation are unlikely to be detrimental to the stabilized layer. Usually the interior of the carbonated specimen is sprayed with phenolphthalein after the UCS test to determine whether the full specimen has carbonated. Typically, materials that have sufficient stabilizer to ensure adequate durability, remain uncarbonated in the interior of the specimen.

This test is not carried out routinely, it is mainly used for research purposes.

(vii) CSIR Erosion Test

A useful test to determine the durability of stabilized materials is the CSIR erosion test, shown in Figure 43. The test involves the wheel tracking of beams of stabilized materials under water and with a grit covered rubber membrane between the wheel and the specimen. The depth of abrasion of the specimen is determined as a measure of the durability of the material. The test method is described in de Beer (1989).

The test has been shown to be useful indicator of the potential performance of cementitious (and coincidentally bituminous) stabilization.



Figure 43. Erosion Test

(viii) Strength Loss versus Mixing Time (Appendix A, Method A.2)

Problems have been encountered where the actual site working time of the stabilized material has exceeded the optimum working time of the material/cement combination. Based on Australian experience, a protocol to investigate

this aspect of the material has been produced for use in South Africa. This is summarised as Method 2 in Appendix A. This protocol is, however, quite arduous and requires commitment by all parties if it is to be successful. It should, however, become a standard test procedure to ensure that correct working times are identified in the field prior to stabilization work.

5.3.2 Field Control Tests

During construction, a number of tests are required:

(i) Degree of Compaction

The degree of compaction is normally controlled using nuclear (SANS 3001–NG1 to NG5) or sand replacement (TMH1 A10(a), will be republished as SANS 3001–GR35) methods to determine the field densities, see Section 2.7. To establish the degree of compaction, the field densities are compared with the MDD determined in SANS 3001–GR51. It is important to ensure that the values determined for the MDD used for comparison are representative of the actual material being tested in the field. This requires that the test is done on material from as close as possible to the field density site and that the sampling and delay before testing represent the actual field conditions adequately. Aspects such as the field temperatures and time of sampling and testing should be simulated as closely as possible.

In the test method, the MDD and OMC can be obtained either by taking untreated material and adding the required stabilizer content or by using the freshly stabilized material, depending on the client's requirements. In addition, moisture contents of field samples are either accepted as sampled or adjusted to achieve OMC, also depending on the client. It is most important that the test laboratory is aware of the particular requirements for each project. The comments in Section 2.7 regarding this test apply.

(ii) Stabilizer Content

Four methods for doing this test are provided in TMH 1:

- **Method A15(a).** Determination of the cement or lime content of stabilized materials by means of the Ethylene Diamine Tetra Acetate (EDTA) test.
- **Method A15(b).** Determination of the cement or lime content of cement stabilizer or lime stabilized materials by means of a flame photometer.
- **Method A15(c).** Determination of the lime content of lime-stabilized material using ammonium chloride.
- **Method A15(d)** (will be republished as SANS 3001-GR58). Determination of the cement or lime content of stabilized materials by means of the back titration (acid base) method.

Of these methods, Method A15(d) (soon to be SANS 3001–GR58) is the most commonly used. These methods are generally based on determining the calcium oxide content of the stabilized material. Experience has shown that the natural variability in the calcium content of many materials can actually be larger than the quantity of calcium oxide added through the stabilizer, which is measured in most of the tests. Where materials with high and/or variable calcium oxide contents are stabilized, the accuracy of the results is thus impaired.

Probably the best way of checking the stabilizer content of the treated material is to physically check the amount of stabilizer added and the volume of material treated. This is relatively simple when bags of stabilizer are added but more complicated when the stabilizer is distributed from a bulk tanker. Mat or pan methods of collecting the applied stabilizer and weighing it are useful alternative methods. In these cases, more reliance has to be placed on physically checking that the correct quantity of stabilizing agent is spread on the road, and that it is thoroughly mixed to the specified thickness and width.

(iii) Strength Tests

Testing for Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) is covered in 5.3.1(iv). Samples of stabilized material are generally collected from the field for the preparation of briquettes for UCS and ITS testing (SANS 3001–GR53 and GR54). The handling of these samples should be such that the field conditions are simulated as closely as possible as described for the compaction/density testing discussed above.

The time between sampling and testing can be critical and often results in a significant difference between design and field test results. The new method, SANS 3001–GR51,



Samples Made from Field Mix

During field sampling for control testing, the samples obtained after addition of the stabilizer and water and after mixing should be returned to the laboratory immediately, for compaction and curing, preferably to be carried out within the same time frame and at the same temperatures as the field placement. It is now accepted practice in Spain to actually compact the specimens in the field during compaction of the layer.

addresses this. Results can also be affected by variations in ambient temperature and humidity. Variations in compaction moisture content, particularly above optimum (possibly due to rain resulting in a field section being over wet), can halve the strengths obtained.

Current specifications can result in a conflict between the minimum ITS and the UCS range required. The continued addition of stabilizer to fine grained materials to achieve acceptable ITS values can result in UCS values exceeding the upper UCS limits. When good quality materials are stabilized, a low percentage passing the smaller sieve sizes can result in high UCS values. It is advisable for C4 and C3 materials, however, to ensure that the ITS criteria are met, even if the upper limit for the UCS is exceeded. Experience has shown that, depending on stabilizer and soil type, the rough relationship between ITS and UCS can vary from 1:7 to 1:15.



UCS and ITS tests

Where UCS and ITS results are in conflict, it is recommended to ensure that the ITS criteria are met, even if, as a result, the UCS upper limit is exceeded.

(iv) Sampling and Preparation of Cored Specimens of Field Compacted Matured Cementitiously Stabilized Material (SANS 3001–GR52)

The coring of a cementitiously stabilized pavement layer is not carried out routinely, but may occasionally be undertaken to obtain specimens for strength testing. Cementitiously stabilized materials tend to be fragile and the operation has to be carried out very carefully to avoid damage to the core specimen.

6. TESTS ON OTHER MATERIALS

Various proprietary stabilizers are available for the improvement of materials that do not meet required standards. The effect on the local materials to be utilised needs to be confirmed prior to and during construction by routine laboratory testing. The quality of the constructed layer must be confirmed after construction.

6.1 Material Stabilization Design

Currently no national standards for the composition or utilisation of non-traditional soil stabilizers exist in South Africa. Guidelines for some materials and specific uses are, however, available (GDPTRW, 2004). A system of accreditation has been developed for non-conventional stabilizers (Jones and Ventura, 2005). This allows a product to be accredited by the Agrément Board on the basis of sufficient successful laboratory and field performance data as well as a limited certification test programme. The Agrément certification process is discussed in Chapter 9: 14.1. It is important to note that the certification of such products indicates only that they have conformed to certain controlled criteria and does not necessarily guarantee that they will perform satisfactorily with all materials under all conditions. Details regarding these tests are summarised in Section 6.3.

To make effective use of non-conventional soil stabilizers, the specified material properties (Chapter 4: 6.2) should be identified and the material/stabilizer combination should be tested to determine whether this specified requirement is met. This would usually be carried out for products that are used for material improvement using a strength test, e.g., CBR, UCS or ITS. If this requirement is achieved under the moisture and density conditions likely to exist in the field, the cost effectiveness of the product should be determined. Unfortunately, no scientifically based life cycle cost experience currently exists in South Africa for these products. The process should thus assume that the product will be effective over the design life of the structure, and the cost must be compared to conventional engineering materials. If there is a significant benefit/cost ratio and the risk is deemed to be acceptable, there is no reason why the product should not be used.

Table 18 provides interim information to assist with decision making regarding the possible use of non-conventional soil additives for both dust palliation and soil improvement.

Table 18. Interim Guide to Use of Non-Conventional Stabilizers

Product	Parameters												
	Comprehensive SA guidelines available	High PI materials (PI > 10)	Medium PI materials (PI 3 – 10)	Sandy materials (PI < 3)	All weather passability	Steep gradients	Heavy vehicles (mine/quarry)	High traffic volumes (> 250 vpd)	Short term applications (deviations)	Long term applications (maintenance) ¹	Spray-on applications	Mix-in applications	Grader maintenance
Wetting agents			✓			✓			✓		✓		✓
Hygroscopic salts	✓		✓										✓
Natural polymers	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓
Synthetic polymers		✓	✓	✓	✓	✓	✓			✓		✓	
Modified waxes			✓						✓		✓		✓
Petroleum resins		✓	✓		✓	✓	✓		✓	✓	✓	✓	
Bitumen	Dependant on characteristics of individual products												

Note:

- Other products can be applied as long term applications, but will require periodic rejuvenation.

6.2 Recommended Test Procedure for Sulphonated Petroleum Products

Considerable work has been done on the use of Sulphonated Petroleum Products (SPPs) as soil stabilizers (Greening and Paige-Green, 2003) and this has been captured in a "Toolkit" (TRL/CSIR/gTKP, 2007). Information regarding the use of these products is discussed fully in this document. However, it is recommended that materials for use with SPP's should be tested as follows and should comply with the requirements discussed:

1. Determine the **indicator and classification properties** of the natural material to be treated, i.e., Atterberg limits, grading, compaction characteristics, soaked CBR strengths.
2. Determine the **reason for treating the product with an SPP**; whether it is to increase the density to improve the stiffness or to "stabilize" the material to improve the strength and waterproof it. This is generally a function of the indicator and classification test results.
3. Carry out an **X-ray diffraction analysis** and **cation exchange capacity** determination to identify the type and activity of the clay minerals.
4. **Evaluate the results** as follows:
 - a. If the material has a low plasticity, low fines content and/or little active clay components (vermiculite, montmorillonite, chlorite or interlayers of these minerals) the "clay stabilization" reaction will not occur and a less concentrated solution of the product (0.01 l/m^2) could be used purely as a compaction aid. However, if there is a high concentration of iron oxides, calcium carbonates or other amorphous material (all identifiable by X-ray diffraction) stabilization reactions may be possible and the suppliers of the products should be asked to modify the formulation for these materials and to recommend an appropriate dosage rate.
 - b. If the material has significant quantities of active clays (described above) and a cation exchange capacity of more than 15 meq/100 g , the material is usually suitable for treatment.
 - c. Materials with properties lying between these two can be successfully treated with many of these products at a concentration of 0.02 l/m^2 .
5. **Carry out a CBR test** at the specified concentration with a selected SPP or preferably with all possible candidate SPP's. This is usually a function of economics. If the stabilization reaction is expected to occur (method b above), allow the CBR specimen to cure for 7 days prior to soaking and testing to establish a conservative strength for the pavement analysis. This curing requirement may differ from product to product and the supplier should furnish the necessary curing requirements.

A number of specifications have been proposed for SPP's in various areas. Based on the evaluation of these, together with field observations, the specifications given in Table 19 have been proposed and found to be effective when used in conjunction with the testing procedures outlined above.

In addition, the following can be used as a rough guide to the application rates of the chemicals, based on the AASHTO soil classification (Chapter 4: 2.3.2) and assuming a treated compacted thickness of 150 mm:

- A1, A3 0.01 l/m^2
- A2-4, A2-5, A4, A5 0.02 l/m^2
- A2-6, A2-7, A6, A7 0.03 l/m^2

It should be noted that many of these products are produced in small and often simple plants using local raw materials. The standards and specifications of the products should also be assessed to ensure that product of consistent and high quality is used for laboratory and field work. Delivered product should have a batch number and quality control certificate from the manufacturers.

A number of products classified as "Enzymes" have also appeared on the market in recent years. These, to all intents and purposes, appear to behave and to be applied in a similar manner to the SPP's and can essentially be tested and treated as described above. However, it appears that the maximum fines content should perhaps be restricted to between 8 and about 35%.



Certification of Proprietary Properties

It is important to note that the certification of proprietary products indicates only that they have conformed to certain controlled criteria and does not necessarily guarantee that they will perform satisfactorily with all materials under all conditions.

A number of the products are cement or bitumen based and these materials should be tested as the equivalent cement or bitumen emulsion treated material would be, and comply with the same UCS or ITS required for an equivalent conventionally treated material (See Sections 5.3 and 4.6).

6.3 Agrément Test Requirements and Protocols

To obtain an Agrément certificate, a number of steps need to be followed. These include various laboratory and field investigations as well as the assessment of the product on two standard materials using a standard test protocol. The two materials consist of a non-plastic sand and a combination of this sand (70%) with a standard black clay (30%) with the properties given in Table 20.

The required tests on these two materials include:

- Abrasion resistance
- Erosion resistance
- Strength improvement

The methods for these tests are provided in Appendix B.

Table 19. Properties of SPP's

General			
Plasticity Index	8 – 35 %	Percentage passing 0.075 mm	15 – 55 %
Bar Linear Shrinkage	> 4 %	Minimum density	98 % MDD
Unsealed Roads			
Minimum CBR in situ at OMC	Traffic		
	for < 50 vpd	for 50 to 250 vpd	For > 250 vpd
	35 %	45 %	55 %
Sealed Roads			
Minimum CBR soaked at specified compaction	SSG ¹ at 93 % MDD	Subbase at 95 % MDD	Base at 98 % MDD
	15 %	45 %	80 %

Note:

1. SSG = selected subgrade

Table 20. Material Characteristics of Sand and Black Clay Mix

Material	Characteristics						
	Maximum size (mm)	P0.425	P0.075	PI (%)	OMC (%)	MDD (kg/m ³)	CBR (%)
Sand	5	82	22	3	8.6	2071	42
Clay	5	80	55	35 – 40	18.2	1700	< 2
70:30 sand:clay	5	81	35	9	14.0	1864	8

Notes:

P0.425 = % passing 0.425 mm sieve

P0.075 = % passing 0.075 mm sieve

OMC = Optimum moisture content at 100% Mod AASHTO compaction effort

MDD = Maximum Dry Density at 100% Mod AASHTO compaction effort

CBR = California Bearing Ratio at 100% Mod AASHTO compaction effort



Snake-Oils

Proprietary products used for stabilization are colloquially known as “snake-oils”. Despite the negative term, if sufficient investigation is done, there is no reason why the products should not be used.

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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.

SAPeM, CHAPTER 3

APPENDIX A: TEST METHODS FOR CEMENTITIOUSLY STABILIZED MATERIALS

A1: Procedure for vacuum carbonation for accelerated carbonation test

A2: Determination of field working time

Note: These tests are additional tests for stabilized materials that are not published in other guideline, manual or method compilation.

A1: PROCEDURE FOR VACUUM CARBONATION FOR ACCELERATED CARBONATION TEST

1. Prepare specimens according to SANS 3001-GR50 and allow to cure as specified.
2. Place the required number of specimens on a porous plate or sieve in clean, dry vacuum chamber(s) such that all surfaces are exposed.
3. Close the chamber with an airtight lid.
4. Apply a vacuum of 80 kPa to the chamber for 10 minutes.
5. Close the valve through which the vacuum was applied and connect the CO₂ cylinder to either this or another valve if available on the chamber.
6. Open the CO₂ valve and slowly let CO₂ into the chamber until it is filled with CO₂. Close the valve and leave for 10 minutes.
7. Repeat steps 4 to 6 another 2 times.
8. Repeat step 4.
9. Connect a hose from a bath of water to the valve and open the valve slowly to allow the vacuum to suck water into the chamber.
10. When the cylinder is full, release the vacuum pump and open the chamber to remove the specimens. Conduct conventional unconfined compressive strength tests (SANS 3001-GR53).

A2: DETERMINATION OF FIELD WORKING TIME

1. SCOPE

This protocol covers the laboratory procedure used for the determination of the maximum allowable working time for a cement stabilized granular pavement material. This should be carried out for each material and cement combination to provide an estimate of the likely time available for construction of the layer. Recent experience in Australia has shown that the UCS is a better indicator than MDD for working time limitations, but the influence of both the UCS and MDD should be assessed. The protocol described can be adapted for the latter. The UCS may be substituted by the Indirect Tensile Strength (ITS) or complemented with the ITS as necessary.

2. DEFINITIONS

Maximum Allowable Working Time for UCS

The working time for unconfined compressive strength is defined as the time measured from the commencement of the addition of the stabilizing agent to the compaction of the stabilized material, which corresponds to 80% of the mean value of three determinations of UCS, for samples compacted one hour after incorporation of the stabilizing agent." The specified temperature is:

- May to September 10 to 15°C
- October to April 20 to 25°C

The working time for maximum dry density is defined as "the time measured from the commencement of the addition of the stabilizing agent to the compaction of the stabilized material, which corresponds to 97% of the mean value of three determinations of maximum dry density, for samples compacted one hour after incorporation of the stabilizing agent.

All samples shall be cured in a loose condition in airtight containers at 23 ± 2 °C.

3. APPARATUS

- 3.1 For grading - as detailed in SANS 3001-GR1.
- 3.2 For unconfined compressive strength - as detailed in SANS 3001-GR50 to 53.
- 3.3 For maximum dry density and optimum moisture content as detailed in SANS 3001-GR31.

4. MATERIAL SELECTION

- 4.1 Obtain a representative sample of the material to be used on the road.
- 4.2 Prepare and precondition the material in accordance with Clauses 3.1 and 3.2 of SANS 3001-GR1.

Note: Obtain sufficient material to determine the maximum dry density, optimum moisture content and for the preparation of 12 UCS or ITS moulded test samples.

5. PROCEDURE

5.1 General

If maximum allowable working time is to be determined for construction being carried out from October to April inclusive, the test shall be performed between 20 and 25 °C.

If maximum allowable working time is to be determined for construction being carried out from May to September inclusive, the test shall be performed between 10 and 15 °C.

However, if it is envisaged that the working temperature will be higher than 25 °C, then the test shall be carried out at that temperature.

5.2 Maximum Allowable Working Time for UCS

- 5.2.1 Mix sufficient quantity of the material with the design cement content for the material for the determination of maximum dry density and optimum moisture content according to SANS 3001-GR31¹. The maximum size of the material shall be 37.5 mm, with no compensation for any oversize material.

- 5.2.2 Place the mixed material in sealed plastic bags and allow to stand for *one hour* at the required temperature (see 5.1 above).
- 5.2.3 After 1 hour break up the cured material over a 37.5 mm screen and recombine material passing and retained on the screen.
- 5.2.4 Determine the maximum dry density and optimum moisture content of the recombined material in accordance with SANS 3001-GR31¹.
- 5.2.5 Mix sufficient quantity of material with the design percentage of the cement to carry out the Unconfined Compressive Strength (UCS) tests in accordance with SANS 3001-GR50 to 53.
- 5.2.6 Place the mixed material in sealed plastic bags and allow to stand for one hour at the required temperature (see 5.1 above).
- 5.2.7 After the 1 hour standing time break up the cured material over a 37.5 mm screen and recombine material passing and retained on the screen.
- 5.2.8 Add water if necessary and mix the material to achieve a laboratory moisture ratio of 95% to 105% of OMC.
- 5.2.9 Determine the UCS of the material in accordance with SANS 3001-GR53 and the following:
 - (i) Compact the specimens in accordance with method SANS 3001-GR50. Complete compaction of both specimens within 30 minutes of mixing in step 5.2.8.
 - (ii) Cure the compacted test specimens (in a sealed plastic bag) for 7 days at the required temperature.
 - (iii) On completion of curing, immediately perform the procedure for compression testing as described in SANS 3001-GR53.
- 5.2.10 Repeat steps 5.2.5 – 5.2.9 for 2, 4, 8, 12 and 24 hours standing time after addition of the cement.
- 5.2.11 Plot UCS versus standing time. Draw the line of best fit to the points and determine, to the nearest hour, the maximum allowable working time for the cement (see Figure A.1 as an example).

5.3 Maximum Allowable Working Time for MDD

- 5.3.1 Mix sufficient quantity of the material with the design cement content for the material for the determination of maximum dry density and optimum moisture content according to SANS 3001-GR50 and 51. The maximum size of the material shall be 37.5 mm, with no compensation for any oversize material.
- 5.3.2 Place the mixed material in sealed plastic bags and allow to stand for *one hour* at the required temperature (see 5.1 above).
- 5.3.3 After 1 hour break up the cured material over a 37.5 mm screen and recombine material passing and retained on the screen.
- 5.3.4 Determine the MDD of the material in accordance with method SANS 3001-GR31.
- 5.3.5 Repeat the process to determine the MDD after conditioning for 2, 4, 8, 12 and 24 hours after addition of the cement.
- 5.3.6 Plot MDD versus standing time. Draw the line of best fit to the points and determine, to the nearest hour, the maximum allowable working time for the cement (see Figure A.1 as an example).

6. REPORT

Report the following information:

- 6.1 The type and amount of cement used, including SANS type, make and brand.
- 6.2 The maximum allowable working time for the cement to the nearest hour (in terms of UCS/ITS and/or MDD).
- 6.3 The temperature range at which the value was determined.
- 6.4 The working time will be the lesser of the times determined for UCS, ITS or MDD.

¹ All reference to compaction and strength testing in this protocol makes use of the material screened at 37.5 mm with no added back crushed oversize or other compensation for oversize material.

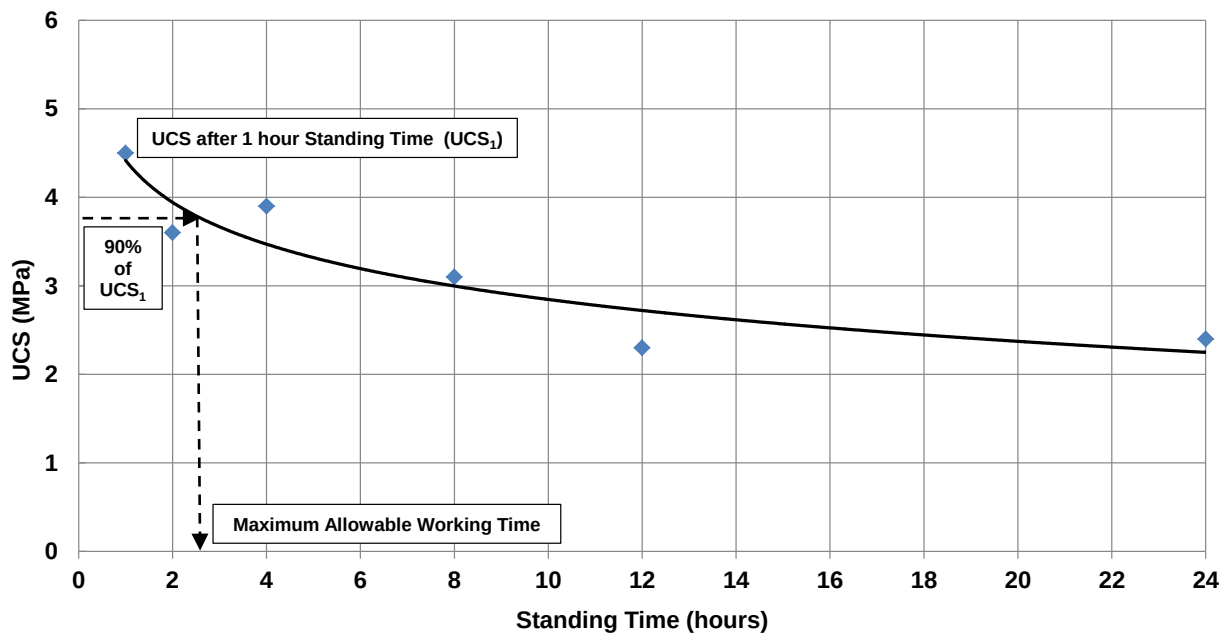


Figure A.1. Unconfined Compressive Strength vs Standing Time (can be modified for ITS and/or MDD)

SAPEM, CHAPTER 3

APPENDIX B: TEST METHODS FOR AGRÉMENT CERTIFICATION OF NON-TRADITIONAL ROAD ADDITIVES

1. Scope

This method covers the determination of the following properties of materials treated with non-traditional road additives:

- Abrasion and erosion resistance
- Change in density
- Moisture sensitivity
- Strength improvement (modified California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS))
- Plasticity change

The tests have been developed as control tests for fit-for-purpose certification of such additives.

2. Apparatus

- 2.1 Balance capable of weighing 5.0 kg having a sensitivity of 0.1 g
- 2.2 100 ml beaker
- 2.3 Spatulas, pans, etc
- 2.4 Stopwatch
- 2.5 Steel mould having an inside diameter of 100 mm and 175 mm in length. Two endcaps 30 mm thick and diameter that will fit snugly into the mould. These are pressed into the mould to form a specimen 100 mm in diameter and 115 mm in height. An extruder used to extract the specimens from the moulds, which fits into a recess machined into the base of the endcap used as a base plate (see Figures B.1 to B.5).
- 2.6 Standard drying oven capable of maintaining a temperature of 50 and 100 °C (± 5 °C)
- 2.7 Soaking bath
- 2.8 Compression testing machine (UCS press)
- 2.9 Perforated aluminium disc, 75 mm in diameter and 3 mm thick
- 2.10 The apparatus required to determine the liquid limit and plastic limit, as given in SANS 3001-GR12.
- 2.11 The apparatus required to determine the optimum moisture content and maximum dry density (OMC/MDD) as given in SANS 3001-GR31 for lime and cement based products, SANS 3001-GR30 for all other materials.
- 2.12 The apparatus required to determine the California Bearing Ratio, as given in SANS 3001-GR40.
- 2.13 A brushing apparatus as described in Sampson (1988) with a standard brush
- 2.14 An erosion resistance testing apparatus (see Figures B.6 and B.7).

3. Specimen Preparation

- 3.1 Abrasion and Erosion Resistance, Moisture Sensitivity and UCS
 - 3.1.1 Prepare the material to be tested using the prescribed procedure in SANS 3001-GR1 or GR2, except that all aggregate retained on the 6.7 mm sieve is discarded.
 - 3.1.2 Determine the OMC at the proposed additive content mixing the required percentage of chemical into the soil and testing the mix according to SANS 3001-GR30 or GR31. It is advisable to add the required quantity of additive to the water to be added to the sample as this will assist with the dispersion of the additive throughout the soil.
 - 3.1.3 Determine the mass of dry material required to fill the mould using data from 2.
 - 3.1.4 Weigh the calculated quantity of chemical by pouring it into the beaker and add the required amount of water to bring the material to OMC.

- 3.1.5 Add the contents of the beaker to the dry material and mix well. Cover the bowl with a moist cloth and let this stand for 120 minutes to allow the moisture to equilibrate throughout the soil and the additive to react. After this, remix the material.
- 3.1.6 Ensure that the mould and attachments are clean. Lubricate the inside of the mould with a spray lubricant (e.g., WD40, Q20) to facilitate extrusion.
- 3.1.7 Place the bottom end cap (recessed) in the mould, attach the bulking tube and then fill the mould with the prepared material. It may be necessary to lightly tamp the material into the mould, as the loose material will have a volume greater than the mould volume. Once all the material is in the mould, remove the bulking tube and position the top cap in the mould.
- 3.1.8 Using the compression machine, press the top end cap into the mould until it is flush with the top of the mould.
- 3.1.9 Extrude the specimen from the mould, weigh it and place it on a carrying plate.
- 3.1.10 Dry/cure the specimen as prescribed by the additive supplier or as per the guidelines provided in Table A.1.
- 3.1.11 Remove the specimens from the oven and allow to cool to room temperature.

Table B.1. Curing Procedure for Various Additives

Product Category	Curing Procedure
Hygroscopic salt	Dry to constant mass at 50 °C. Place specimen on a stand 50 mm above a basin of water in an environment with a temperature of at least 25 °C and relative humidity of at least 50% and allow to reabsorb atmospheric moisture for 24 hours prior to testing.
Natural polymer	Dry to constant mass at 50 °C
Synthetic polymer	Dry to constant mass at 50 °C
Modified wax	Dry to constant mass at a temperature 5 °C below congealing point of wax
Petroleum resin	Dry to constant mass at 50 °C
Bitumen and tar	Dry to constant mass at 50 °C
Sulphonated oil	Follow product specification or dry to constant mass at 50 °C
Enzyme	Follow product specification or dry to constant mass at 50 °C

3.2 Density Change and CBR

- 3.2.1 Prepare the material to be tested using the prescribed procedure in SANS 3001-GR1 or GR2, except that aggregate retained on the 6.7 mm sieve is discarded.
- 3.2.2 Determine the OMC at the proposed additive content mixing the required percentage of additive into the soil and testing the mix according to SANS 3001-GR30 or GR31. It is advisable to add the required quantity of additive to the water to be added to the sample as this will assist with the dispersion of the additive throughout the soil.
- 3.2.3 Determine the mass of dry material required to fill the mould using data from 2.
- 3.2.4 Weigh the calculated quantity of additive by pouring it into the beaker and add the required amount of water to bring the material to OMC.
- 3.2.5 Add the contents of the beaker to the dry material and mix well. Cover the bowl with a moist cloth and let this stand for 30 minutes to allow the moisture to equilibrate throughout the soil. After this, remix the material.
- 3.2.6 Prepare moulds and compact specimens as described in SANS 3001-GR30 or GR31.
- 3.2.7 Dry/cure the specimen as prescribed by the additive supplier. If the specimen must be dried back, place the specimen in an oven at a temperature of 50 °C (± 5 °C) until constant moisture content is reached (approximately 48 hours).
- 3.2.8 Remove the specimens from the oven and allow to cool to room temperature.

3.3 Plasticity Change

- 3.3.1 Prepare material as described in SANS 3001-GR12, but add the additive to the distilled water at the rate specified by the supplier prior to mixing it into the soil fines.

4. **Method**

4.1 Abrasion Resistance

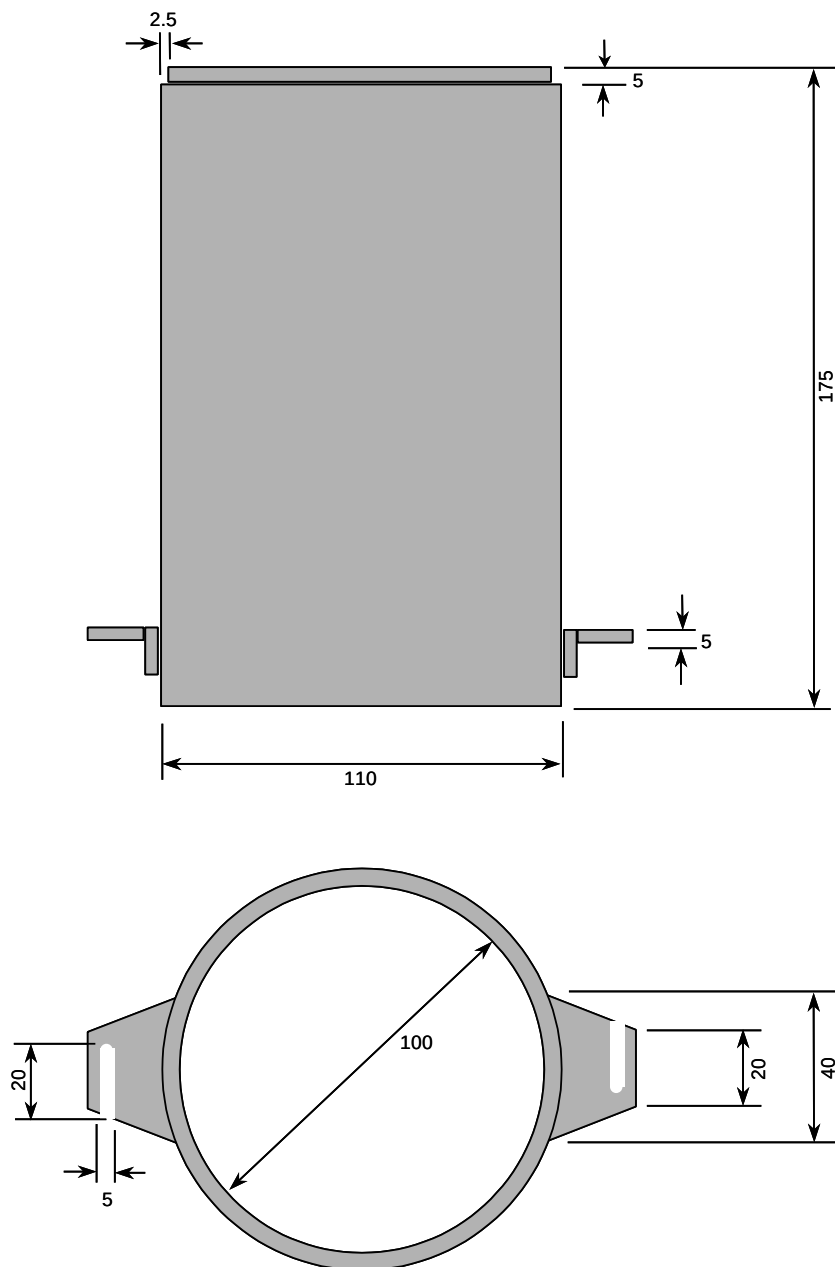
- 4.1.1 Weigh the specimen.
- 4.1.2 Place the specimen in the mechanical brushing machine, ensuring that the specimen is not damaged and that no material is removed.
- 4.1.3 Set brush weight to 2.0 kg and counter to 250.
- 4.1.4 Place the brush on the specimen and brush for 250 revolutions.

- 4.1.5 Remove the specimen and weigh.
- 4.1.6 If the specimen has been treated with an additive, repeat steps 4.1.2 to 4.1.6 to give 500 revolutions.
- 4.1.7 Record the amount of material lost after 250 and 500 revolutions as a percentage of the original weight (recorded in 1).
- 4.2 Erosion Resistance
 - 4.2.1 Weigh the specimen.
 - 4.2.2 Place the specimen into the plastic holder and clamp onto the erosion resistance testing apparatus using the strap and wing nuts provided.
 - 4.2.3 Position the erosion tester in a laboratory sink and open the tap supplying water to the constant head apparatus (water container) such that water flows slowly out of the overflow pipe. Open the tap at the bottom of the water container (which is connected to the erosion device by a rubber hose), allowing water to be jetted onto the surface of the specimen. At the same time start the stopwatch.
 - 4.2.4 After five minutes have elapsed turn off the tap to the erosion device and then the tap to the water container.
 - 4.2.5 Carefully remove the specimen holder from the erosion apparatus and gently place the specimen onto a pan, ensuring that it is not damaged in any way.
 - 4.2.6 Place the pan in the oven set at 105 °C and allow to dry for 24 hours or to constant mass.
 - 4.2.7 Weigh the specimen.
 - 4.2.8 Record the amount of material lost as a percentage of the original weight (recorded in 1).
- 4.3 Density Change
 - 4.3.1 Test as described in SANS 3001-GR30
- 4.4 Moisture Sensitivity
 - 4.4.1 Place aluminium marker disc in the centre of the treated specimen and the specimen on an aluminium pan.
 - 4.4.2 Place the pan in the water bath, start the stopwatch and check that the water cover is approximately 25 mm above the specimen.
 - 4.4.3 Observe the rate of disintegration.
 - 4.4.4 Stop the stopwatch as soon as the specimen has disintegrated to the edge of the marker disc.
 - 4.4.5 Record the time (moisture sensitivity in minutes).
 - 4.4.6 If the specimen has not disintegrated to the marker disc after 120 minutes of soaking, remove the specimen from the water bath.
 - 4.4.7 Record the moisture sensitivity as >120 minutes.
 - 4.4.8 Surface-dry the soaked specimen with a paper towel.
 - 4.4.9 Immediately proceed with the UCS test.
- 4.5 UCS
 - 4.5.1 Place the specimen in the compression testing machine and load at an approximate rate of 100 N per second until failure.
 - 4.5.2 Record the load at failure.
 - 4.5.3 Place the crushed material in a moisture tin and weigh.
 - 4.5.4 Dry the sample in an oven set at 105 °C for 24 hours.
 - 4.5.5 Determine the moisture content.
- 4.6 CBR
 - 4.6.1 Test as described in SANS 3001-GR40.
- 4.7 Plasticity Change
 - 4.7.1 Test as described in SANS 3001-GR10 or 11.

FIT FOR PURPOSE CERTIFICATION - CONTROL TESTING											Page 1 of 3	
Additive name:						Field application rate:						
100 x 175 mm specimen preparation										Start Date		
Material type			Sand			Clay			% of MDD			
OMC						Dry weight of soil						
MDD (100% Mod AASHTO)						Water (%)						
Additive quantity		g	ml				Water (g)					
Specimen			1 Control		2 Control		3 Control		4 Treated		5 Treated	
Date			Abrasion resistance									
Specimen weight - wet (g)												
Curing - hours @ x°C												
Initial dry weight (g)												
Weight after 250 revs (g)												
Loss (%)												
Weight after 500 revs (g)												
Loss (%)												
Average loss (%)												
Date			Erosion resistance									
Specimen weight - wet (g)												
Curing - hours @ x°C												
Initial dry weight (g)												
Weight after test (g)												
Loss (%)												
Average loss (%)												
Date			Moisture sensitivity									
Specimen weight - wet (g)												
Curing - hours @ x °C												
Time to disintegrate (mins)												
Average time (mins)												
Date			Unconfined compressive strength									
Load at failure (kN)												
UCS (kPa)												
Weight (wet)												
Weight (dry)												
Moisture content (%)												
Average UCS (kPa)					Average moisture content							

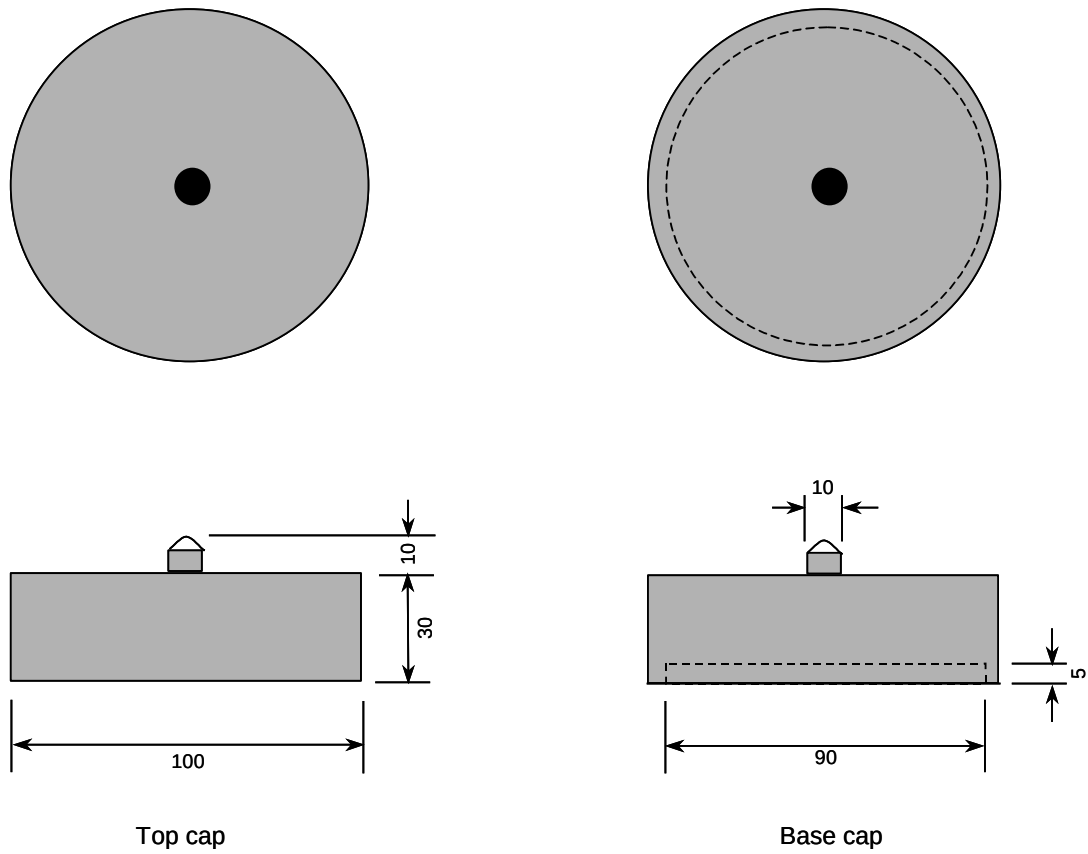
FIT FOR PURPOSE CERTIFICATION - CONTROL TESTING											Page 2 of 3			
Additive name:							Field application rate:							
152 x 152 mm specimen preparation (CBR)										Date				
Material type			Sand				Clay				% of MDD			
OMC							Dry weight of soil							
MDD (100% Mod AASHTO)							Water (%)							
Additive quantity		g	mℓ						Water (g)					
Specimen			1 Control		2 Control		3 Control		4 Treated		5 Treated		6 Treated	
Date				Density change										
Max dry density @ 95%														
Optimum moisture content														
Average density														
% Increase over control														
Date				California Bearing Ratio										
Specimen weight - wet (g)														
Curing (eg hours @ x°C)														
Specimen weight - dry (g)														
Load at 2.54 mm (kN)														
CBR (%)														
Load at 5.08 mm (kN)														
CBR (%)														
Load at 7.62 mm (kN)														
CBR (%)														
Swell (%)														
Average CBR (2.54 mm)														
% Increase over control														
Average CBR (5.08 mm)														
% Increase over control														
Average CBR (7.62 mm)														
% Increase over control														
Average swell														

FIT FOR PURPOSE CERTIFICATION - CONTROL TESTING										Page 3 of 3	
Additive name:						Field application rate:					
Additive quantity:		g	mℓ				Material type:			Clay	X
Specimen			1 Control	2 Control	3 Control	4 Treated	5 Treated		6 Treated		
Date			Liquid limit								
Container No											
Mass container + wet soil											
Mass container + dry soil											
Mass container											
Mass moisture											
Mass dry soil											
Number of taps											
Liquid limit											
Date			Plastic limit								
Container No											
Mass container + wet soil											
Mass container + dry soil											
Mass container											
Mass moisture											
Mass dry soil											
Plastic limit											
Date			Plasticity index								
Plasticity index											
Average liquid limit											
Average plastic limit											
Average plasticity index											
Technician:							Date:				
Signature:											
Checked by:							Date:				
Signature:											
Notes											



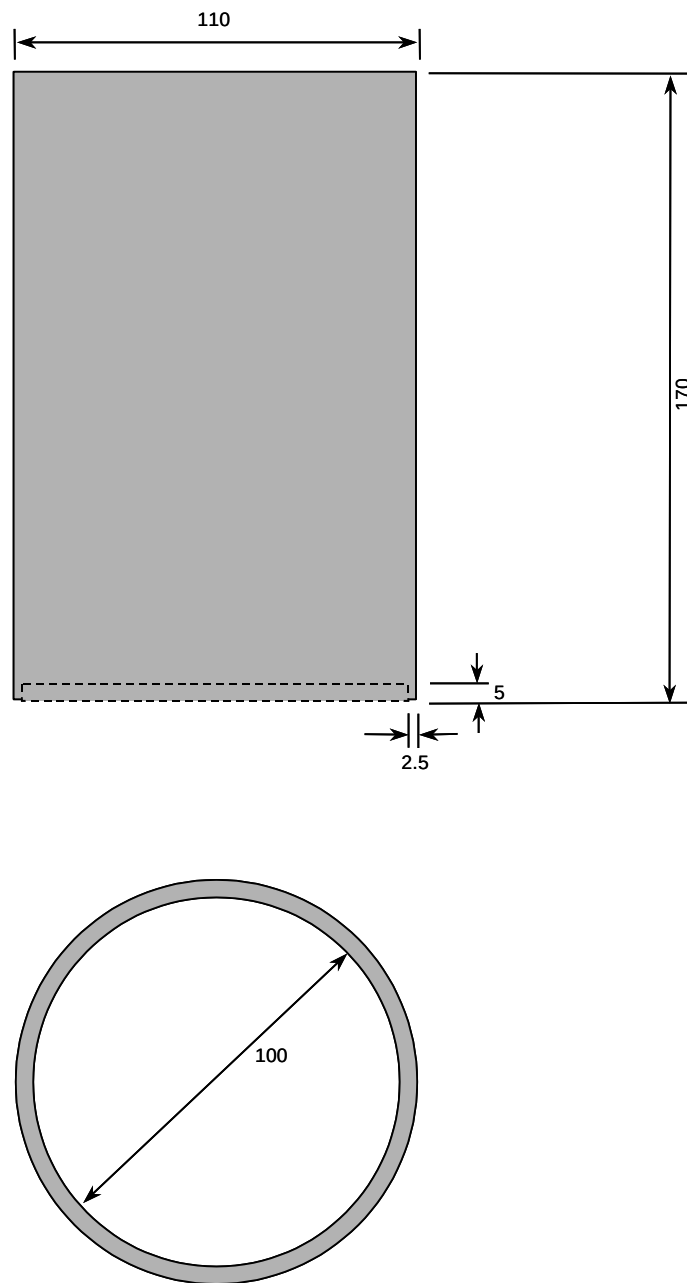
Scale 1:2
Dimensions in mm
Material: mild steel
Quantity: 1

Figure B.1. Mould for Compacting Abrasion and Erosion Resistance and Modified UCS Specimens



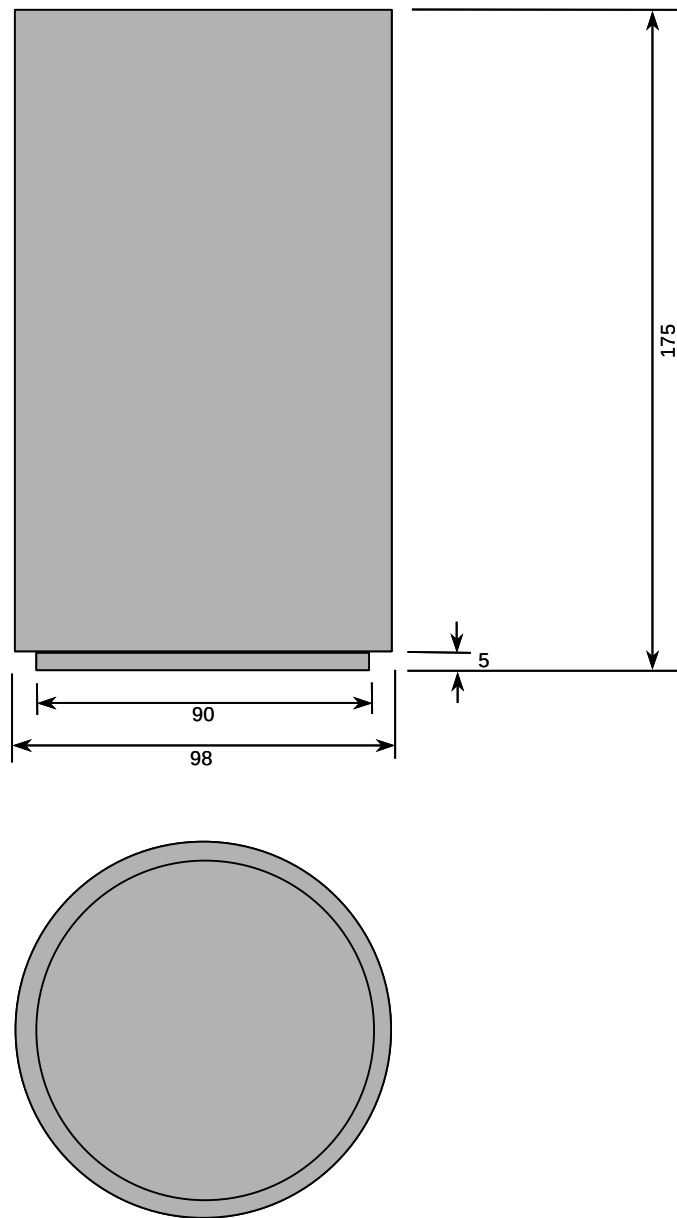
Scale 1:2
 Dimensions in mm
 Material: mild steel
 Quantity: 1 each

Figure B.2. Endcaps for Mould for Compacting Abrasion and Erosion resistance and Modified UCS Specimens



Scale 1:2
Dimensions in mm
Material: mild steel
Quantity: 1

Figure B.3. Bulking Tube for Mould for Compacting Abrasion and Erosion Resistance and Modified UCS Specimens



Scale 1:2
Dimensions in mm
Material: aluminium
Quantity: 1

Figure B.4. Extruder for Mould for Compacting Abrasion and Erosion Resistance and Modified UCS Specimens



Figure B.5. Photograph of Mould and Specimen

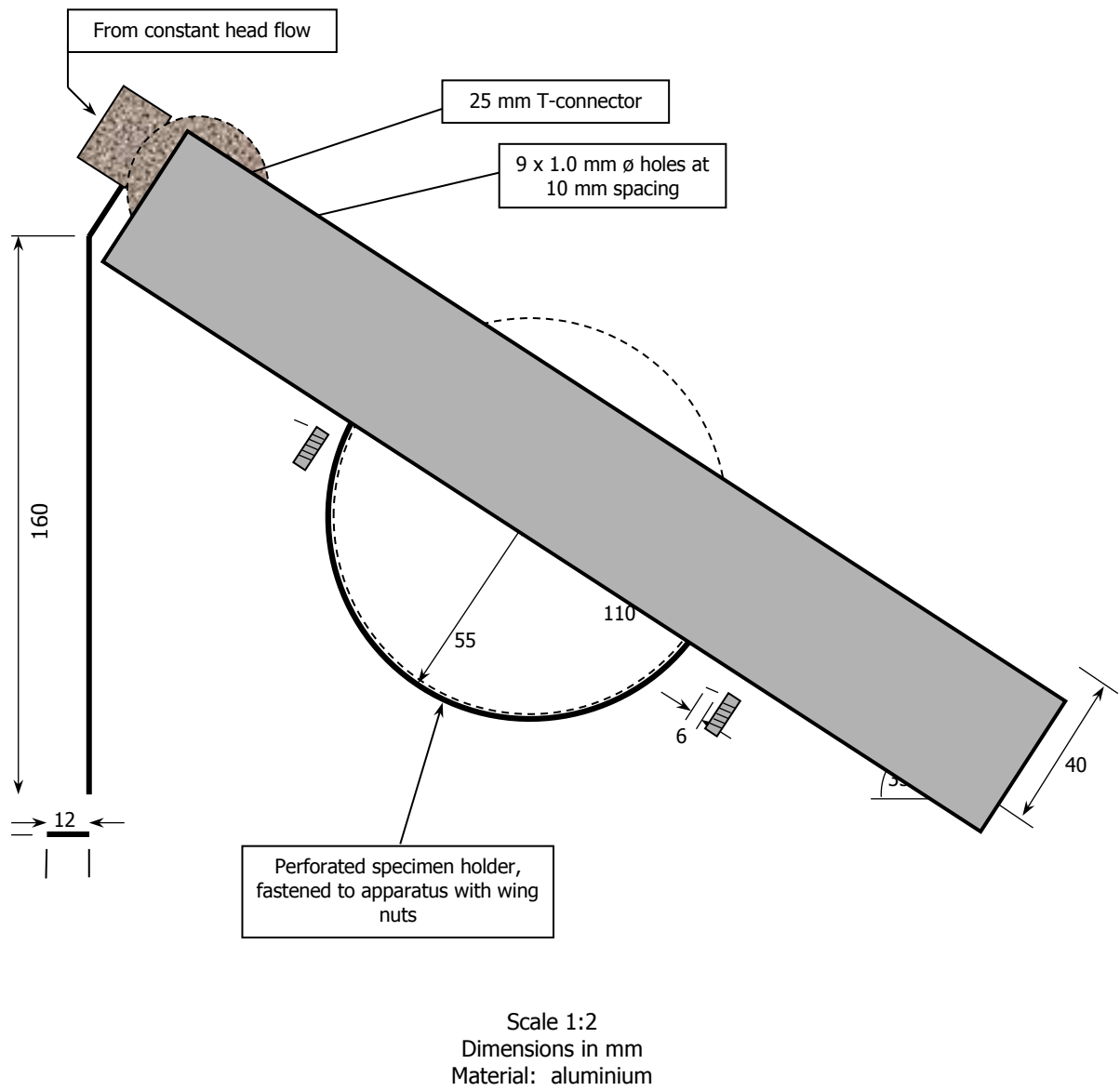


Figure B.6. Erosion Resistance Test Apparatus (Side View)

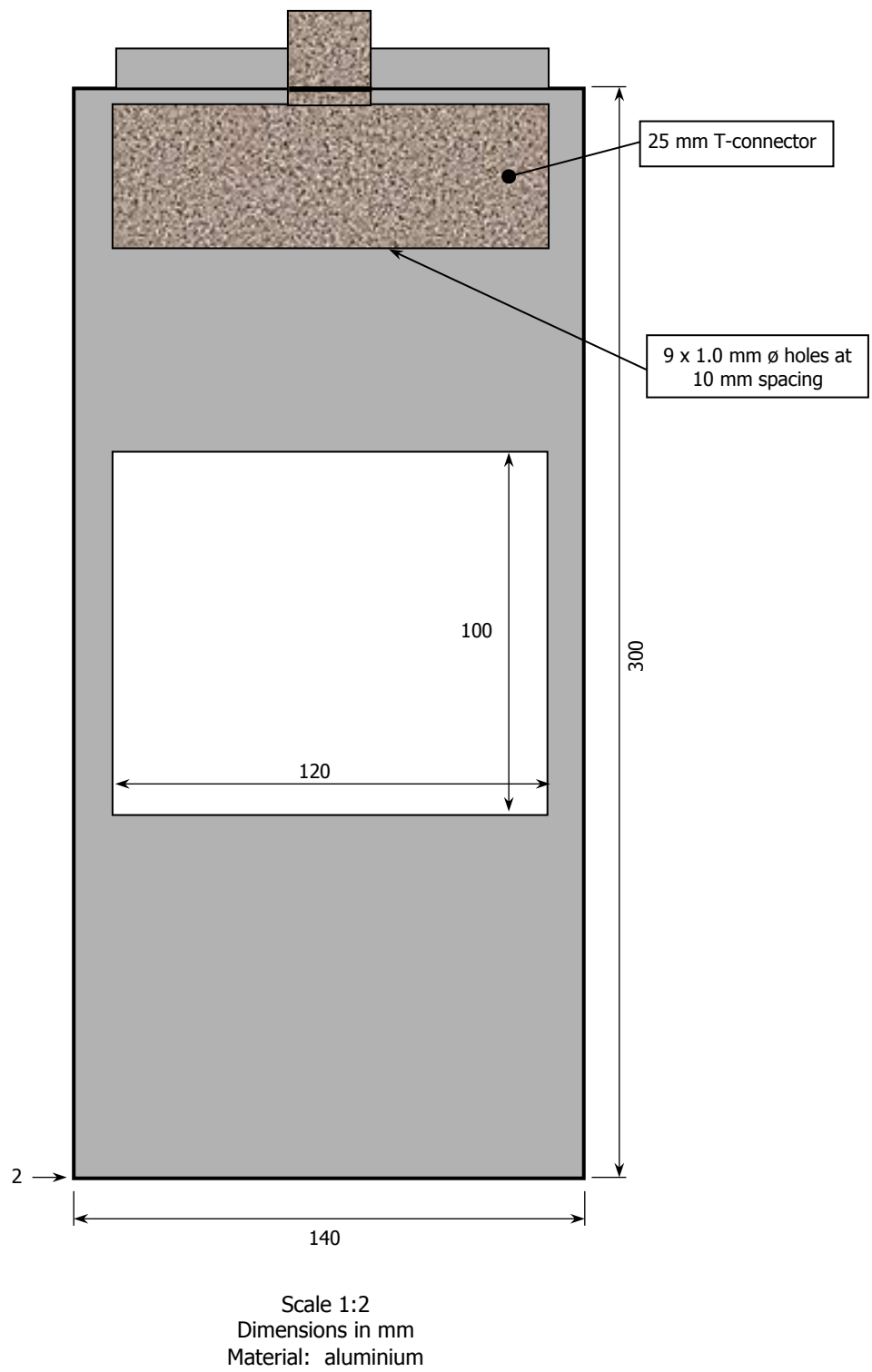


Figure B.1. Erosion Resistance Test Apparatus (Plan View)



Figure B.7. Erosion Resistance Testing Apparatus

SAPEM, CHAPTER 3

APPENDIX C: TEST METHOD NUMBERS, MIGRATION TO SANS 3001

- Status as of September 2014.
- Most of the methods are similar to the traditional TMH1 with minor changes and amendments. The moisture determination is intended for use throughout the SANS 3001 methods.
- Minor amendments have been made to rationalise apparatus dimensions such as mould sizes. The changes to some of the sieve sizes appear to be significant but all are less than 7 % and do not affect the outcome as they give a slightly altered position on the grading curve.
- The MDD is different primarily because scalping of the sample on the 37.5 mm sieve is given as the reference method for preparing the sample, although the procedure for crushing the coarse material to pass the 20 mm sieve is also given.
- Concrete tests are omitted from this list as they are currently being reviewed by the SABS concrete subcommittee SC59A.

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
GRAVELS (GR)							
A1(a) & A5	GR1	Wet sieve and preparation of fines	Published 2008, 2013	Sieve sizes rationalised	Similar	Similar, with < 0.075 mm incorporated	Sieve sizes e.g., 4.75 mm to 5 mm
A1 (b)	GR2	Dry sieve	Published 2009, 2011	Sieve sizes rationalised	Similar	Dry only < 5 mm – sieve to 0.425 mm	0.075 mm fraction not determined
A6	GR3	Hydrometer	Published 2012	Similar	Similar	Different – close to ASTM & BS	While the principles remain the same the test is more complicated
	GR5	Preparation of air-dried fines	Published 2012				New
A2 & A3	GR10	Atterberg limits & linear shrinkage	Published 2008, 2013	Similar	Similar	One point liquid limit, plastic limit and linear shrinkage	Reintroduces LS from old TMH1 Method same but splitting up LL methods
A2 & A3	GR11	Liquid limit only – refers to GR10 for plastic limit and linear shrinkage	Published 2008, 2013	Similar	Similar	Two point liquid limit only	
A2 & A3	GR12		Published 2008, 2013	Similar	Similar	Flow curve liquid limit only	
	GR20	Moisture content	Published 2008, 2010	Instead of describing moisture content method in each test method – provides generic for all situations			New
A7	GR30	Maximum dry density	Published 2010, 2013	Similar	Allows for scalped > 37.5 (ref) or crushed < 20	Similar with greater detail of moisture content points	Differs in sample preparation of > 20 mm
	GR31	Maximum dry density (MDD) of stabilized material – laboratory mixed	Published 2010, 2013	Similar to A7	Modified preparation	Similar to A7	Uses GR30 with modifications to allow for stabilization

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
A20 & A21T	GR32	Electrical conductivity and pH of saturated soil-paste	Draft				
B17T	GR33	Sulphates in fine aggregates	Draft				
A10(a)	GR35	Sand replacement field density	With SANS	Similar	Similar	Similar	Minor amendments
A8	GR40	California Bearing Ratio (CBR)	Published 2010, 2013	Similar	Scalped > 37.5	Similar – C effort 5 layers x 11 blows	Differs in sample preparation of > 20 mm
A9	GR41	CBR of Lime treated material	With SANS	Similar	Similar	Similar to GR40	Uses GR40 with modifications to allow for stabilization
A14	GR50	Preparation, compaction and curing of laboratory stabilized	Published 2010, 2013	Similar	Similar to GR31 with curing details added	Similar to GR30	Principal difference is that curing details have been added
A14	GR51	Sample, preparation, compaction & curing of laboratory stabilized	Published 2010, 2013	Similar	Similar	Similar but allows two MDD methods	Prescribes curing methods and provides alternative MDD methods
	GR52	Sample and preparation of field cores	Published 2010				New
A14	GR53	Unconfined Compressive Strength (UCS)	Published 2010	Similar	Similar	Similar	
A16T	GR54	Indirect Tensile Strength (ITS)	Published 2010	Similar	Similar	Similar	
A19	GR55	Wet-dry brushing by hand	Published 2012	Similar	Similar	Similar	Same procedure but with greater detail provided
	GR56	Wet-dry brushing by mechanised brushing	With SANS				New
	GR57	ICL or ICC of stabilized materials	Published 2014	Similar	Similar	Similar	Same procedure but with greater detail provided
A15(d)	GR58	Cement or lime content – back titration	With SANS	Similar	Similar	Similar	
AGGREGATES (AG)							
B4	AG1	Particle size analysis	Published 2009, 2014	Sieve sizes rationalised	Similar	Similar	
B18(a)	AG2	Average least dimension (ALD) direct measurement	Published 2009	Similar	Similar	Similar	
B18(b)T	AG3	ALD by computation	Published 2009	-	-	Complex calculation	Old nomogram replaced with calculation procedure
B3	AG4	Flakiness index	Published 2009, 2014	Similar	Similar	Similar	

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
B19	AG5	Sand Equivalent	Published 2013	Similar	Similar	Similar	
B7	AG9	Treton impact values	Draft	Similar	Similar	Similar	For gravel roads
B1 & B2	AG10	Aggregate crushing value (ACV) & 10% FACT	Published 2012	Similar	Similar	Similar	Procedure combines tests and determines loads for second and third points differently
SABS 5848	AG11	Polished Stone Value (PSV)	With SANS	Similar	Similar	Similar	New
SABS 5839	AG12	MgSO ₄ Soundness	With SANS	Similar	Similar	Similar	Procedure similar but detail significantly revised
	AG13	Venter test	Published 2013				New - Based on COLTO 8107 (e)
	AG14	Ethylene glycol durability	Published 2014				New
	AG15	Ethylene glycol plus 10 % FACT	Published 2012				New
	AG16	Durability mill index	Published 2014				New
B14	AG20	Apparent and bulk density and water absorption > 5 mm	Published 2011	Similar	Similar	Similar	
B15	AG21	Apparent and bulk density and water absorption < 5 mm	Published 2011	Similar	Similar	Similar	Similar but permits alternative calculation of bulk density
-	AG22	Apparent density crushed stone base	Published 2012				New - Based on COLTO 8108 (b)
SABS 5844	AG23	Particle and relative densities	Published 2012	Similar	Similar	Similar	
B6	AG40	Organic impurities	Depends on SC59A sub-committee of SABS for Concrete				
B12	AG41	Soluble deleterious impurities					
	AG42	Detection of sugar					
	AG43	Shell content					
	AG44	Deleterious clay content (Methylene blue)					

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
NUCLEAR DENSITY GAUGES (NG)							
	NG1	Admin, handling and maintenance	Published 2014				New
	NG2	Validation of standard calibration blocks	Published 2014				New
	NG3	Calibration of a nuclear gauge	Published 2014				New
	NG4	Verification of a nuclear gauge	Published 2014				New
A10(b)	NG5	Determination of in situ density	Published 2014	Similar	-	Different	
BITUMEN STABILIZED MATERIALS (BSM)							
	BSM1	Foamed bitumen characteristics	With SANS				New
BITUMEN (BT)							
	BT10	Ball penetration test for seals	Published 2014				New
	BT11	Texture depth test for seals	Published 2012				New
	BT12	Marvil water permeability test	Published 2012				New – replaces COLTO 8109 (d)
TMH2	BT20	Certification of a binder distributor	Published 2010				Replaces TMH2
TMH2	BT21	Validation of a binder distributor dip stick	Published 2010				Replaces TMH2
TMH2	BT22	Power and road speed indicator tests for BD	Published 2010				Replaces TMH2
TMH2	BT23	Pump system performance of a binder distributor	Published 2010				Replaces TMH2
TMH2	BT24	Measurement of transverse distribution (Bucket test)	Published 2011				Replaces TMH2
ASPHALT (AS)							
Appendix to C2	AS1	Making of asphalt briquettes	Published 2011	Similar with specified compaction block	Similar	Similar	Similar but with a number of small variations
C2	AS2	Determination of Marshall stability, flow and quotient	Published 2011	Similar	Similar	Similar	Similar but with a number of small variations
	AS3	Gyratory compaction of asphalt briquettes	Draft				New

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
	AS4	Indirect Tensile Strength	With SANS				New
	AS5	Dynamic creep of bituminous mixtures	Draft				New
	AS24	Modified Lottman moisture susceptibility	Draft				New
C3	AS10	Bulk density and void content (Marshall)	Published 2011	Similar	Similar	Similar	Similar but with a number of small variations
C4	AS11	Maximum voidless density and absorbed binder (Rice's)	Published 2011	Similar	Similar	Similar	Similar but with a number of small variations
C7(b)	AS20	Binder content – extraction with organic solvent	Published 2011	Similar	Similar	Similar	Similar but with a number of small variations
	AS21	Binder content – ignition method	With SANS				
C8T	AS22	Bitumen content of slurry	Published 2014	Similar	Similar	Similar	
C11	AS23	Moisture content in asphalt mix	Published 2014	Similar	Similar	Similar	
PROCEDURES (PR)							
	PR1	Uncertainty of measurement, repeatability, reproducibility and bias	Published 2008, 2011				New
	PR2	Repeat, check or duplicate tests	Published 2011				New
	PR3	Interlaboratory testing	Draft				New
	PR5	Computation of soil mortar percentages, coarse sand ratio, grading modulus and fineness modulus ¹	Published 2009, 2011				New - Computations extracted from a number of methods
	PR10	Checking, handling & maintenance of sieves	Published 2009, 2011				New
PAVEMENT DEFORMATION (PD)							
	PD1	MMLS3 testing of asphalt mixes	With SANS				New

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
FRESH CONCRETE (CO1)							
SANS 5861-1	CO1-1	Mixing fresh concrete in the laboratory	With SANS				
SANS 5861-2	CO1-2	Sampling of freshly mixed concrete	With SANS				
SANS 5862-1	CO1-3	Consistence of freshly mixed concrete — Slump test	With SANS				
SANS 5862-3	CO1-4	Consistence of freshly mixed concrete — Vebe test	Draft				
SANS 5862-4	CO1-5	Consistence of freshly mixed concrete — Compacting factor and compaction index	Draft				
SANS 5862-2	CO1-6	Consistence of freshly mixed concrete — Flow test	Draft				
SANS 6250	CO1-7	Density of compacted freshly mixed concrete	With SANS				
SANS 6252	CO1-8	Air content of freshly mixed concrete — Pressure method	Draft				
TESTS CARRIED OUT ON HARDENED CONCRETE (CO2)							
SANS 5860	CO2-1	Dimensions, tolerances and uses of cast test specimens	With SANS				
SANS 5861-3	CO2-2	Making and curing of test specimens	With SANS				
SANS 5863	CO2-3	Compressive strength of hardened concrete	Draft				
SANS 6255	CO2-3	Compressive strength of mortar	Draft				
	CO2-4	Specification for testing machines for the measurement of the compressive strength of concrete	Draft				
SANS 5864	CO2-5	Flexural strength of hardened concrete	Draft				

TMH1	SANS 3001	Description	Status	Apparatus	Sample	Procedure	Comments
SANS 6253	CO2-6	Tensile splitting strength of hardened concrete	Draft				
SANS 6085 & 6254	CO2-7	Initial drying shrinkage and wetting expansion of concrete	Draft				
SANS 6251	CO2-8	Density of hardened concrete	Draft				
CONCRETE STRUCTURES							
	CO3-1	Durability Index Tests - Part 1: Preparation of test specimens	Draft				
	CO3-2	Durability Index Tests - Part 2: Oxygen permeability	Draft				
	CO3-3	Durability Index Tests - Part 3: Chloride conductivity	Draft				
	CO3-4	Durability Index Tests - Part 4: Water sorptivity	Draft				
SANS 5865	CO3-5	Drilling, preparation, and testing for compressive strength of cores taken from hardened concrete	With SANS				

Notes

- SM = Soil-mortar percentages (coarse sand, fine sand, coarse fine sand, medium fine sand, fine fine sand, silt and clay).
CSR = Coarse sand ratio (coarse sand fraction : soil fraction (minus 2 mm)).
GM = Grading modulus
FM = Fineness modulus