SOUTH AFRICAN

PAVEMENT ENGINEERING MANUAL

Chapter 3

Materials Testing

THE SOUTH AFRICAN NATIONAL ROADS AGENCY LTD

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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 the 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.**

The authorities and publications relevant to the methods used in South Africa to test road building materials are given in Table 1.

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)

Some of these test methods can be found in draft TMH6: 1986 Special Methods for Testing Roads (TMH6, 1984). This document also contains test methods for texture depth, longitudinal regularity, ball penetration, and the measurement of seismic velocities. COTO is in the process of compiling guidelines for network level management of performance measurements. 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)

Table 1. Authority for Test Methods for Road Building Materials Used in South Africa

Publication/Authority	Details
TMH1: 1986 Standard Methods of Testing Road Construction Materials (TMH1, 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.TIP Check 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) methods.
COLTO Standard Specifications for Road and Bridge Works for State Road Authorities (COLTO, 1998)	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 (TG1, 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 (TG2, 2009)	Test methods for **bituminously stabilised 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

The testing of existing pavement structures is discussed further in Chapter 5.

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.

TMH1 to SANS
All TMH1 test methods are currently being revised and translated into SANS methods. To check the latest situation regarding publication, go to www.sabs.co.za and find the Web Store page. Under "Quick Search Criteria" enter "3001" to get a list of methods published to date.

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 being 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.

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

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: 1986 "Standard Methods for Testing Road Construction Materials". 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
- 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.

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**

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.

Changes in Sieve Sizes
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.

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 as in the different climatic regions. Under different drainage regimes, different soils will be formed from the same original rock formation.

As these processes have been ongoing for millions of years, it becomes apparent that soils may bear very little resemblance to the original rock from which they were formed. In all likelihood they will consist of a mixture of materials from a variety of origins. It is also obvious that soils 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.

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**".

Soils and Gravels

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

Soils: Large proportion of fine materials.

Standards applicable to soils and gravels are covered in Chapter 4, Section 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 Section 2.3 of Chapter 4. In South Africa, the TRH14 (1985) 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 COLTO 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	Comments	Chapter Reference
	G4	G5	G6	G7	G8	G9	G10			
Grading (sieve analysis)	✓	✓	✓	✓	✓	✓		SANS 3001-GR1 SANS 3001-GR2	COLTO specifies GM[1] on G7 to G9 quality materials	Section 2.3
								Hydrometer	Hydrometer analysis	Section 2.3
Atterberg Limits	✓	✓	✓	✓	✓	✓		SANS 3001-GR10 SANS 3001-GR12	TRH14 and COLTO requirements	Section 2.4
Strength (CBR)	✓	✓	✓	✓	✓	✓	✓	SANS 3001-GR40	TRH14 and COLTO requirements	Section 2.7
Swell (CBR)	✓	✓	✓	✓	✓	✓	✓			
Flakiness Index	✓							SANS 3001-AG4	COLTO requirement	Section 3.2.2
Durability										
Venter Test	✓	✓	✓	✓	✓	✓		COLTO Section 8100	COLTO requirements for mudrock include Venter Test and 10% FACT.	Section 1.1
10% FACT (wet)	✓	✓	✓	✓	✓	✓		SANS 3001-AG10		
Durability Mill Index	✓							SANS 3001-AG16[2]	COLTO requirement	
Soluble Salts										
pH	✓	✓	✓	✓	✓	✓		TMH1 A20	TRH14 and COLTO requirements.	Section 2.9
Electrical conductivity	✓	✓	✓	✓	✓	✓		TMH1 A21T		

Note
1. Grading Modulus
2. This test method has been submitted to SANS, but as of November 2001, not yet published.

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:

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

Where: P = percentage passing a sieve with aperture d
D = maximum particle size

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.

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.

Variability in Gradings
Allowance needs to be made for the variability in materials and thus gradings. Materials should therefore not be rejected on grading alone but in conjunction with the lack of other critical properties such as density and strength.

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.

Three different test protocols can be used to obtain the grading of soils and gravels: Wet preparation, dry preparation and the hydrometer method.

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

In this reference method (SANS 3001-GR1), 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.

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.

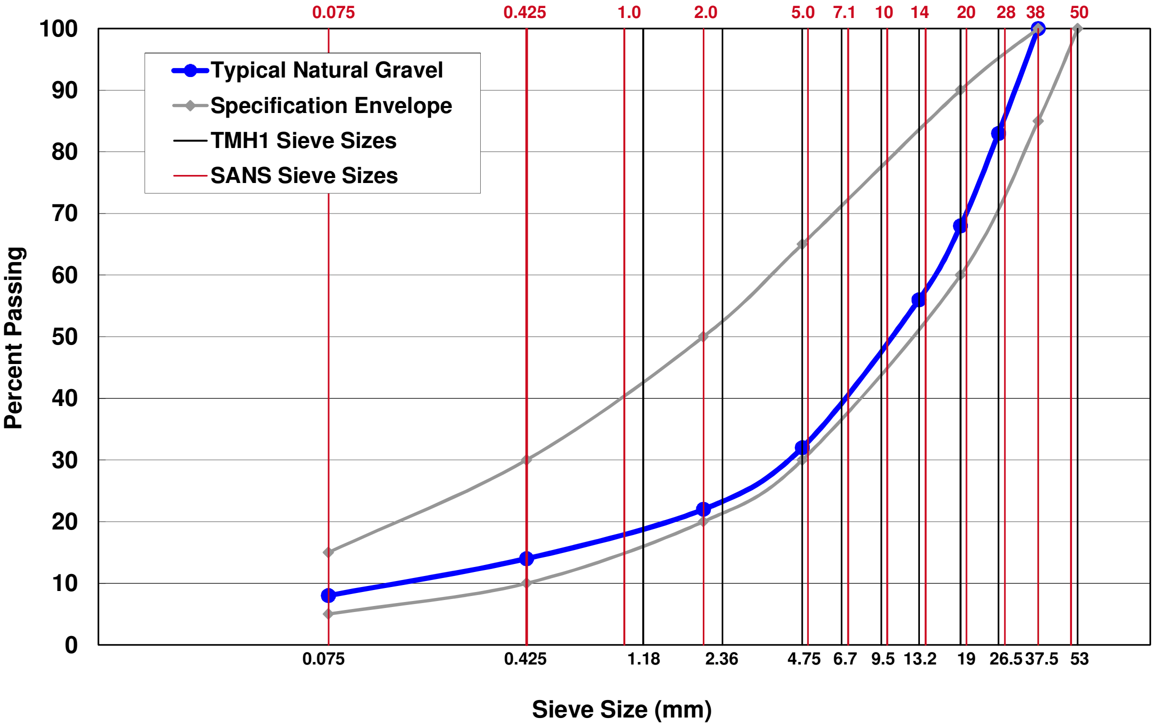


Figure 1. Typical Grading of a Natural Gravel

Figure 2. Sieves for Grading Determination

(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 (TMH1 A6)

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 currently (TMH1). ASTM and BS 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.

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.

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 the formula in Equation 2.

$$\mathrm{GM} = \frac{\mathrm{P2.00mm} + \mathrm{P0.425mm} + \mathrm{P0.075mm}}{100} \qquad (2)$$

Where P2.00mm, etc, denote the percentage *retained* on the indicated sieve size.

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

2.4 Atterberg Limit Tests

Atterberg Limit tests measure 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 mm) of a sample. 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 3.

$$\mathrm{PI} = \mathrm{LL} - \mathrm{PL} \qquad (3)$$

Where: PI = Plasticity Index
LL = liquid limit
PL = plastic limit

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 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.

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 1.0% are described as "slightly plastic" (SP).
To determine the Atterberg limits, the flow curve method (SANS 3001-GR12) is the reference method; however the one-point method (SANS 3001-GR10) is normally used for routine and duplicate testing.

Figure 5 illustrates the determination of the liquid limit.

2.5 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.

Indicator Tests

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

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 while the moisture content required to achieve this density at the specified Proctor compaction effort is known as the material's "optimum moisture content".

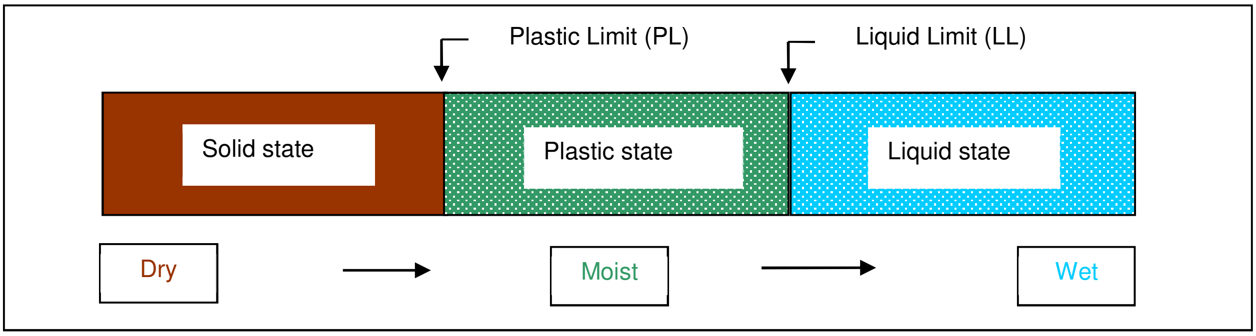


Figure 4. Atterberg Limits

Figure 5. Apparatus and Testing of Atterberg Limits

This test is still used in dam earthworks construction but has been superseded in the road building industry by a similar type of test where a much higher compactive effort is applied to the material in three layers in a larger, 150 mm diameter mould. Maximum dry density and optimum moisture content values are determined in the same way. This is commonly known as the Modified AASHTO density, and 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 used as 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 used as an indicator of the best moisture content for compacting the material 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.

Figure 6. Soil Compaction Equipment

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 these applications, the field sample is prepared by scalping it on the 37.5 mm sieve and discarding the coarser material.

This MDD test is not accurate for cohesionless sand. The MDD of sand should be determined by filling a mould containing water with the sand. The water level is kept above the sand and the mould is vibrated until it is filled to the top with the sand. The dry mass of the sand, vibrated in the mould, is used to determine the MDD. TMH1 method 11T can be used to determine the maximum dry density and optimum moisture content of cohesionless sand.

Cohesionless Sands

The MDD test is unsuitable for cohesionless sands and other methods must be used.

2.6 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.

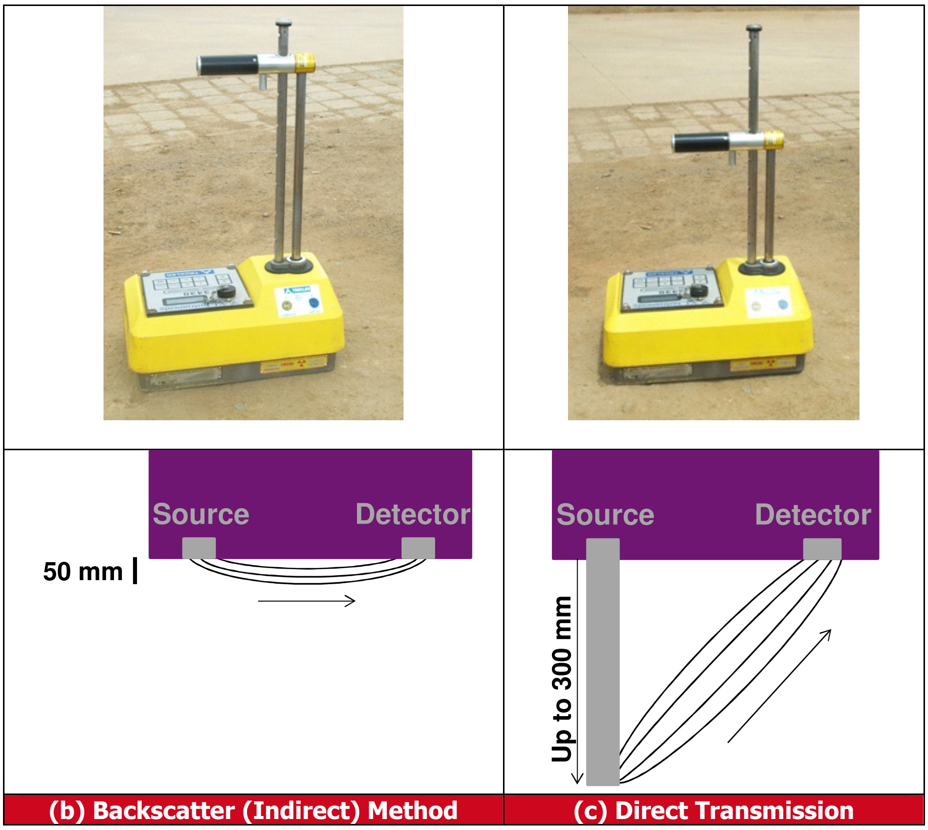
2.6.1 Nuclear Method

This 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.

Density Measurements

Density measurements do not give exact measures of density. Be sure to take the measurements according to the test methods to get most accurate measurement.

Nuclear density gauges do not provide a direct reading of the density of a material. The gauge emits gamma radiation from a Cesium source in backscatter mode (indirect) or from a probe (direct) that passes through the material. The radiation passed through the material 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.



(b) Backscatter (Indirect) Method

(c) Direct Transmission

Figure 7. Nuclear Measurements

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.

Using Nuclear Devices

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

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).

All density measurements on non-bituminous pavement layers should be done using direct transmission. Individual 1 minute readings taken repeatedly at the same position will vary by up to 0.5 %. Variations for 15 second readings will be at least double the 1 minute readings and are not recommended for general use. While standard gauges in backscatter mode or thin layer gauges may be used on bituminous layers as construction control their use

Moisture Contents for Density Measurements

It is advisable to determine the moisture content at each point by the gravimetric method when calculating the dry density of the layer at the test point.

is not recommended for final density determinations. Experience indicates that the gauge readings are affected by temperature, the density of the underlying layer and the hydrocarbons present in the bitumen.

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 bituminously 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). 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. However, it should be frequently checked on subsequent construction sections.

2.6.2 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%.

2.7 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 are. 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.

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 4. 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 4. 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

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 19.0 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.

2.8 Durability Tests

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

- **Venter Test.** This is a COLTO requirement for determining the soundness of mudrock and shale. The test is carried out by soaking particles in water, and then over drying them. This cycle is repeated five times, after which the particles are inspected. The pattern of disintegration is evaluated, and classified into one of five classes. The test method is included in COLTO Section 8100.
- **10% FACT.** This is also a COLTO requirement to determine the durability of mudrock and shale. The same procedure described in SANS 3001-AG10, where the load required to produce 10% of fines is determined, except that the particles are soaked in water for 24 hours before the loading is carried out.
- **Durability Mill Index** (DMI). This test is COLTO requirement for G4 quality materials. It consists of tumbling the particles, together with steel balls in a rotating drum. After the required number of rotations has been completed, the material is graded and the extent to which the material has been disintegrated is used to calculate the Durability Mill Index as well as the percentage of material passing the 0.425 mm sieve. The apparatus for the durability mill is shown in Figure 9. In November 2011, the test method was still in draft form, and had been submitted to SANS. When published by SANS, the test method number will be SANS-AG16.

Figure 9. Durability Mill Apparatus

2.9 Testing of Deleterious Materials

Testing of deleterious materials is done by determining the soluble salts and the pH:

- 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 (6.7 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.

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.

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 the position in the road pavement where they are used. 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 stabilised materials (BSMs) are covered in Section 4, while tests for aggregates used in concrete are included in Section 5.

Standards for aggregates are covered in Chapter 4, Section 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 used as a stabilised 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 would affect the performance of the material in the base layer. Reference is made to COLTO's 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 5, 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. The grading of these materials is strictly controlled to be within prescribed envelopes. COLTO sets 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%

Table 5. Test Requirements for G1, G2 and G3 Materials

Property and Test	Test Method	Comments	Chapter Reference
Deleterious materials[1]: pH Electrical conductivity Sulphate tests Visual inspection	TMH1 A20 TMH1 A21T SANS 3001-AG30/31[2]	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) Ethylene glycol test	SANS 3001-AG10 SANS 3001-AG11 HMA (2001)	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 should be greater than 0.75.	3.2.5 3.2.6
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.	2.3
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 TRH12.	3.2.4

Note
1. Deleterious materials have sulphides, soluble salts and mica
2. Method being drafted for SANS, not yet published.

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. COLTO specifies that the test should be carried out on two fractions of the aggregate, on the fraction passing 28 (25) mm and retained on 20 (19) mm, and the passing 20 (19) mm retained on 14 (13.2) mm fraction. The apparatus is shown in Figure 10.

The sample is also visually examined for fractured faces; COLTO specifies that all the faces of G1 quality aggregate should be fractured, while 50% of G2 and G3 quality aggregate retained on the 5 (4.75) 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 2.4. Note that COLTO requires 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 COLTO, and is only recommended for G2 and G3 materials in TRH14.

3.2.5 ACV and 10% FACT Tests (SANS 3001 – AG10 and AG11)

These tests assess the strength properties of aggregates. The test configuration is similar for both these tests, the basic difference being that the ACV determines the percent of fines produced under a prescribed load and the 10% FACT test determines the load necessary to produce 10% fines. The apparatus is shown in Figure 11. While COLTO gives 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) and 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.

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.

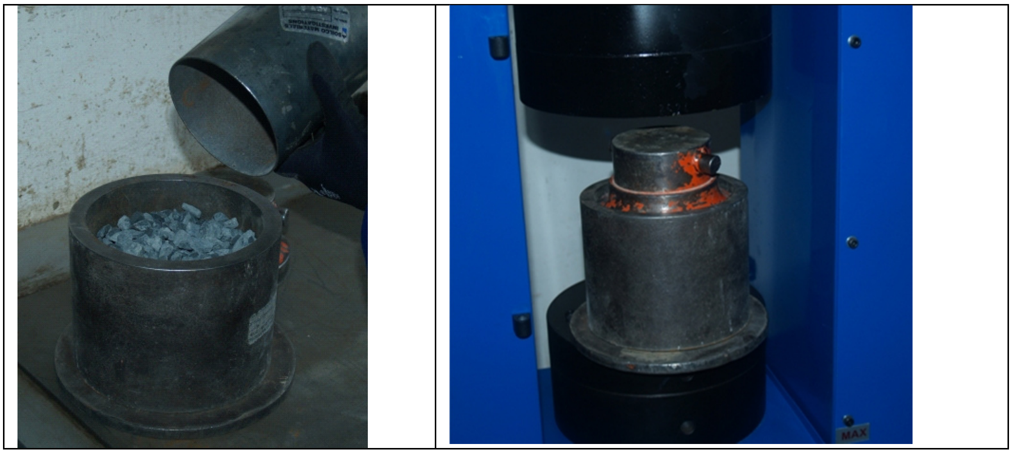


Figure 11. ACV and 10% FACT Apparatus

3.2.6 pH and Electrical Conductivity Tests (TMH1 Methods A20 and A 21T)

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

3.2.7 Ethylene Glycol Soak Test (HMA, 2001)

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

3.2.8 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 2.6. 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:

- **Apparent density** 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. The apparent density is used as reference for G1 quality aggregate. The percentage is known as the apparent relative density (ARD).
- **Bulk density** 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, known as the bulk relative density (BRD).

ARD vs BRD

Apparent Relative Density (ARD) is the reference density for G1's, and the Bulk Relative Density (BRD) for G2's and G3's.

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

Waterbound Macadam

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

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.

4. TESTS ON BITUMINOUS MATERIALS

Bituminous materials are materials that are treated with bitumen, either as hot-mix asphalt or as a stabilised material. Bituminous materials are some of the most expensive and behaviourally complex materials used in the construction of pavements. 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 Stablised Materials (BSMs).

Standards applicable to bituminous materials are covered in Chapter 4, Section 3.

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.

4.1 Tests on Bituminous Binders

Tests required for bituminous binders vary according to the type of binder, as summarised in Table 6. 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 to 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 (1981) 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 (2007).

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 (2007):

- 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 (see test method below), and is commonly supplied in the following grades

- 40/50 pen
- 60/70 pen
- 80/100 pen
- 150/200 pen

Pen Test

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

Typically, the selected 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 bitumens are listed in Table 6 and discussed below.

(i) Penetration Test (ASTM D5)

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 307.

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 second at 25°C. the test equipment is shown in Figure 12.

Figure 12. Penetration Test Equipment

Table 6. Tests Carried Out on Bituminous Binders

Binder Type	Property Tested	Test Standard	Chapter Reference
Penetration grade bitumen	Penetration	ASTM D5	4.1.1
	Softening Point	ASTM D36	
	Dynamic Viscosity (at 60°C and 135°C)	ASTM D4402	
	Rolling Thin Film Oven Test (RTFOT)	ASTM D2872	
	n-Heptane/Xylene Spot test	AASHTO T102	
Cutback bitumen	Kinematic viscosity	ASTM D2170	4.1.2
	Distillation test	ASTM D402	4.1.2
	Penetration (on residue of distillation)	ASTM D5	4.1.1
Bitumen emulsions	Water content	ASTM D244	4.1.3
	Particle charge: (anionic)	SANS 309	
	(cationic)	SANS 548	
	Saybolt Furol viscosity	ASTM D244	
	Coagulation value test	SANS 309 & 548	
	Sieve test	SANS 309 & 548	
	Sedimentation test	SANS 309 & 548	
Modified binders	Flash Point	ASTM D93	4.1.4
	Modified rolling thin film oven test	MB-3[1]	
	Elastic recovery of polymer modified binders by ductilometer	MB-4	
	Torsional recovery of polymer modified binders	MB-5	
	Storage stability of polymer modified binders	MB-6	
	Modified Vialit adhesion test	MB-7	
	Pull out test method for surfacing aggregate	MB-8	
	Pliers test for assessment of adhesion properties	MB-9	
	Ball penetration and resilience of bitumen-rubber blends	MB-10	
	Compression recovery of bitumen-rubber binders	MB-11	
	Flow test for bitumen-rubber binders	MB-12	
	Dynamic viscosity of bitumen-rubber binders	MB-13	
	Softening point of modified binders by ring and ball method	MB-17	
	Dynamic (apparent) viscosity of polymer modified binders	MB-18	
Modified Bitumen Emulsions	Recovery of residue of modified bitumen emulsions	MB-20	4.1.5
	Viscosity of modified bitumen emulsions by means of the Saybolt- Furol viscometer	MB-21	
	Water content of modified bitumen emulsions	MB-22	
	Residue on sieving of modified bitumen emulsions	MB-23	
	Particle charge of modified bitumen emulsions	MB-24	
Precoating fluids	Saybolt Furol viscosity	ASTM D244	4.1.6
	Distillation test	ASTM D402	
	Dynamic viscosity	ASTM D4402	
	Stripping test	Riedel & Weber (TMH1 B11)	

Notes:
1. Test methods designated "MB" are from TG1 (2007).

(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 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.

(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. 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 using SC-4 type spindles. The SI unit of dynamic viscosity is the Pascal second (Pa.s).

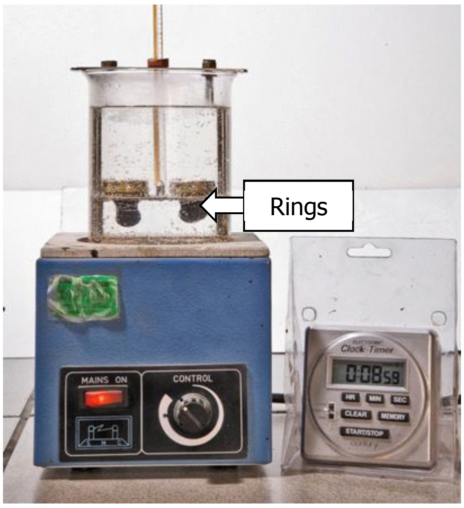


Figure 13. Ring and Ball Test Equipment

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

This test exposes bitumen to ageing and hardening due to the effect of heat and oxidisation 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, 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.

Oxidation

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

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.

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 14. Brookfield Viscometer

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 intial viscosity is required, such as in the construction of sand seals.

The tests used for cutback bitumens are listed in Table 6 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. MC30 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 and the product of efflux time and viscometer calibration factor gives the kinematic viscosity in Stokes.

(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 asphaltic product.

Figure 17. Kinematic Viscosity Testing Equipment

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 progress 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 stabilise 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 6 and discussed below.

(i) Water Content Test (ASTM D244)

This test method measures the amount of water present in the emulsified asphalt, 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 309 and 548)

This test distinguishes between cationic and anionic 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.

(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 309 and 548)

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 m sieve. The mass of materials retained expressed as a fraction of the binder in the emulsion sample used is the coagulation value.

(v) Sieve Test (SANS 309 and 548)

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.

Cationic and Anionic Emulsions

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

Figure 19. Sieve Test for Emulsions

(vi) Sedimentation Test (SANS 309 and 548)

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 (2007). The tests used for modified binders are listed in Table 6 and discussed below. The MB methods are included in TG1 (2007).

(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. 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.

Figure 20. Flash Point Test

(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.

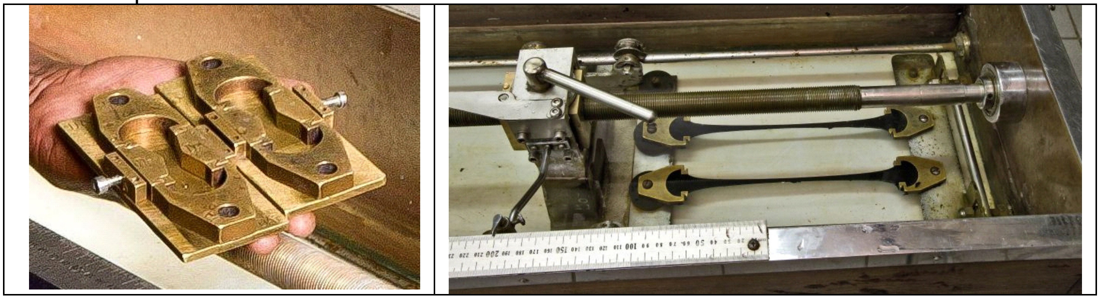


Figure 21. Ductility Tests

(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 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 cylindrical specimen that has been stored in a heated oven for three days are determined 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 arough guide for comparing the adhesion properties of different modified binders.

The test method involves placing quartzite aggregates are placed 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.

Modified Vialit Adhesion Test

This test does not provide reliable results for decision making.

(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 guildelines given in the test method. As a preokinary 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 in this test. 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 25.

Figure 24. Flow Test

(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 24.

(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 on a sample 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 6 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 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.

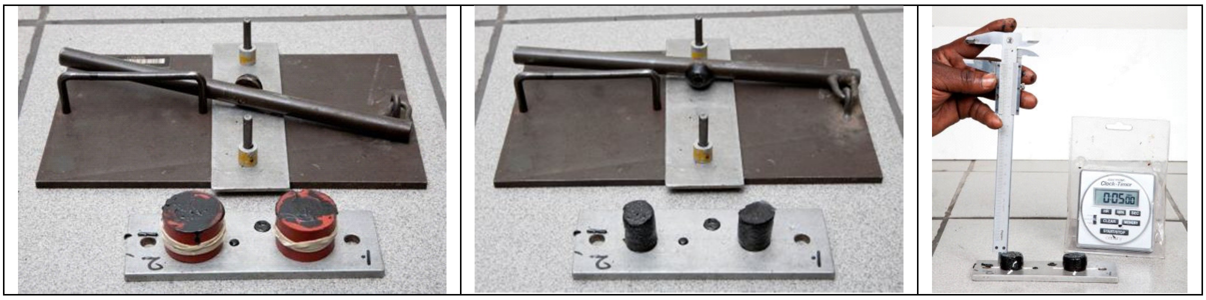


Figure 25. Compression Recover Test Equipment

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) for significance and method.

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

This test distinguishes between cationic and anionic emulsions. SANS 548, which 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 6 and discussed below.

(i) Viscosity Test (ASTM D244)

The viscosity of a precoating fluid is monitored by means of this test 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 indicatory.

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 four 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 "RA" is used in the manufacture of recycled asphalt mixes.

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 above 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 0. Many of the tests have been discussed earlier in this chapter. The additional tests are described in this section.

Table 7. Test Requirements for Asphalt

Application	Test/Property	Test Method	Chapter Reference
Aggregate	Grading	SANS 3001-AG1	2.3
	Flakiness	SANS 3001-AG4	3.2.2
	Polished stone value	SANS 5848	4.2.2
	Sand equivalent	TMH1 B19:	4.2.2
	Water absorption	TMH1 B14 & B15	4.2.2
	Bitumen adhesion	TMH1 B11	4.1.6
	ACV	TMH1 B1 (SANS 3001-AG10)	3.2
	10% FACT	TMH1 B2 (SANS 3001-AG10)	3.2
	Clay lumps and friable particles	ASTM C142 – 97	4.2.2
	Ethylene Glycol	HMA	3.2
Rolled in chips	Grading	SANS 3001-AG1:	2.3
	ACV	TMH1 B1 (SANS 3001-AG10)	3.2
	10% FACT	TMH1 B2 (SANS 3001-AG10)	3.2
	Polished stone value	SANS 5848	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	Make Marshall briquettes	SANS 3001 – AS1	4.2.5
	Determine unit weight of aggregate	AASHTO T 19/T 19M-93	4.2.5
	Void content of fine aggregate	ASTM C1252	4.2.5
Asphalt Mix	Marshall flow, stability and quotient	SANS 3001 – AS2	4.2.5
	Bulk relative density and void content of compacted asphalt	SANS 3001 – AS10	4.2.5
	Maximum voidless theoretical relative density of mixes and quantity of binder absorbed by aggregate	SANS 3001 – AS11	4.2.5
	Soluble binder content and particle size analysis		4.2.5
	Immersion Index	SANS 3001 – AS20	4.2.5
	Asphalt content by ignition method	TMH1 C5	4.2.5
	Hamburg Wheel-tracking Device (HWTD)	ASTM D6307	4.2.5
	Indirect Tensile Strength (ITS) Test Moisture Moisture	Tex-24-F	4.2.5
	Sensitivity Test (Modified Lottman)	ASTM D6931-07	4.2.5
	Cantabro Abrasion Test	AASHTO T283	4.2.5
	MMLS for permanent deformation and susceptibility to	COLTO	4.2.5
	moisture damage	DPG1 Stellenbosch University	4.2.6
	Coring of hot mix asphalt		

Notes:
Tests given in brackets are with SABS awaiting publication as part of the 3001 series.
There may be equivalent tests listed generally under SANS (SABS).
The new SANS 3001 series supersedes equivalent TMH1 and other SANS methods.

(i) Polished Stone Value (SABS SM 848)

This polished stone value (PSV) test is applicable to aggregates used for rolled-in chip 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 to 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.

(ii) Sand Equivalent (SANS 5838)

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

The test sample consists of fine aggregate passing the 5 (4.75) mm sieve. A measured quantity of the oven dried sample is transferred into a transparent measuring cylinder. A solution, known as the "working solution", consisting of calcium chloride, glycerine and formaldehyde diluted in water, 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 is the cylinder has been reached. The cylinder and contents are then 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.

(iii) Water Absorption (SANS 3001 – AG 20 and SANS 3001 – 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, when 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 0, and are discussed below.

(i) Bulk Density in Toluene (BS 812)

This test is used in assessing 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.

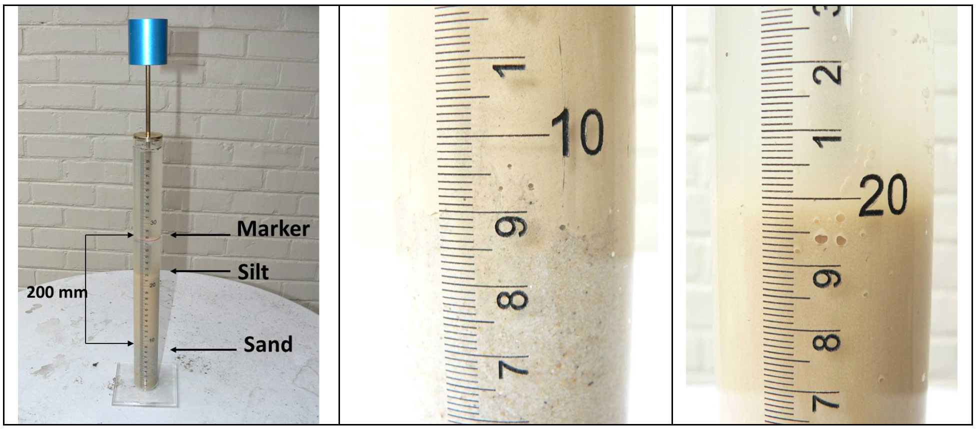


Figure 27. Sand Equivalent

(ii) Voids in Compacted Filler (BS 812)

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

In this 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 smectities, 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, the reader is referred to TRH21 (2009). 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 are very important.

4.2.5 Tests on Mix Components and Mixes for Design

This section will deal exclusively with:

- Tests performed on mix components for design purposes
- Tests on asphalt mix specimens to assess performance characteristics

The tests on asphalt listed in 0 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 users with 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 analysis are also conducted on specimens during mixture design and evaluation of 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 the selection of 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.

Figure 28. Marshall Compaction

(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.

(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 a set temperature, 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".

Figure 29. Marshall Stability and Flow Test

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

The bulk relative density (BRD) is defined in Section 3.2.8. 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 in determining 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.

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.

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 Theoretical Relative 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 in the calculation of 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 is submerged by 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.

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

This method is used for the quantitative determination of 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.

(viii) Immersion Index (TMH1 C5)

The immersion index is determined by soaking Marshall briquettes for 24 hours 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.

(ix) Asphalt Content of Hot Mix Asphalt by Ignition Method (ASTM D6307)

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.

SANS 3001 – AS20

This test is not suitable for mixes with bitumen-rubber. Refer to SABITA Manual 19 (1997) 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.

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.

(x) Hamburg Wheel-tracking Device (HWTD) (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 in the design of asphalt mixes and in the assessment of the properties of laid asphalt.

The HWTD 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 commonly used test temperature is 50 °C, although

40 °C has been used when testing certain base mixtures.

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

(xii) Moisture Sensitivity Test (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.

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.

(xiii) 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 load 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 and the test bed can be sprayed with water so that the mix's susceptibility to stripping can be evaluated

(xiv) Cantabro Abrasion Test (COLTO)

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 the porous asphalt mixes.

4.2.6 Coring of Hot Mix Asphalt

The compaction of hot mix asphalt is routinely carried out 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.
- **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.

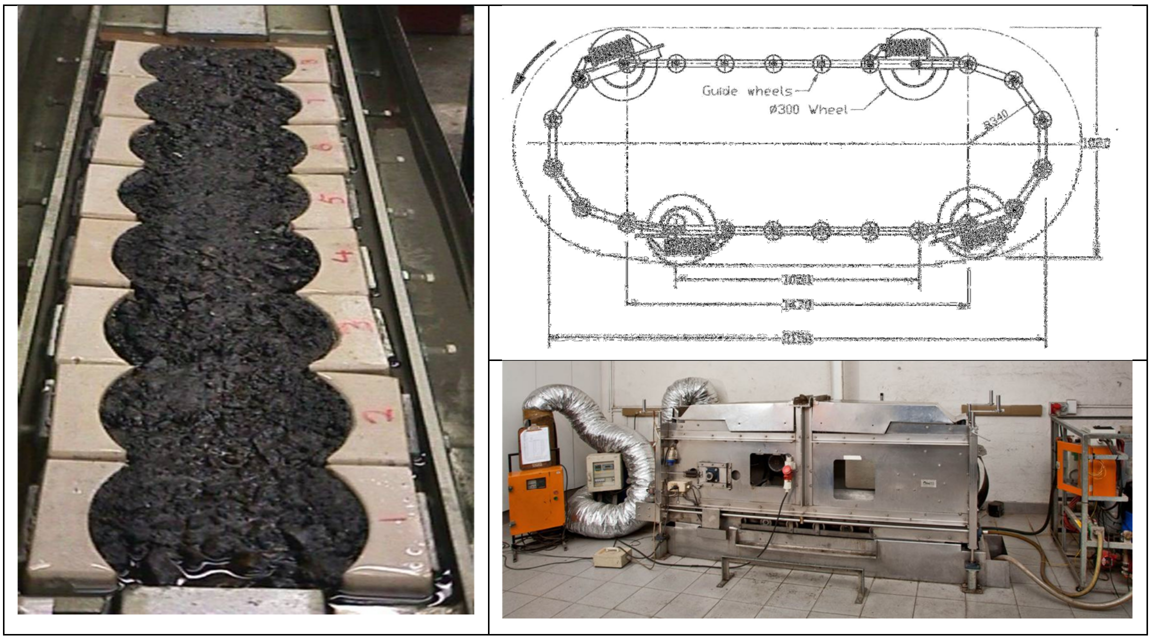


Figure 32. MMLS3

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" (Asphalt Academy, 2001)

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 void-less density**

The compaction of hot mix asphalt layers may also be assessed using a nuclear gauge. Nuclear devices, popularly known as "thin surface gauges" have been developed especially for this purpose. Generally the guidelines given in Section 2.6.1 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.

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 covered, and are given in 0 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 0 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 3000 complying with SANS 208
- **Bitumen emulsion**: anionic premix grade or cationic premix grade

If bitumen emulsion is selected, it should comply with:

- **Anionic** emulsions: SANS 309

- **Cationic** emulsions: SANS 548

The testing of the cutback bitumen and the 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 6 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, Section 5. Surfacing seals can be conveniently divided into:

- **Spray seals:** alternating applications of stone ships 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 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 8.

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

Table 8. Test Requirements for Aggregates Used in Surfacing Seals

Application	Test/Property	Test Method	Chapter Reference
Spray seals: Surfacing seal chips	Grading Flakiness ACV 10% FACT Polished stone value (PSV) Average least dimension (ALD)	SANS 3001-AG1 SANS 3001-AG4 TMH1 B1 (SANS 3001-AG9) TMH1 B2 (SANS 3001-AG9) SANS 5848 SANS 3001-AG2, AG3	2.3 3.2.2 3.2.5 3.2.5 4.2.2(i) 4.4.1.1
Slurries and micro-surfacings: Crusher dust, sand	Grading ACV Sand equivalent Immersion Index Plasticity (Atterberg limits) Methylene blue test	SANS 3001-AG1 TMH1 B1 (SANS 3001-AG9) TMH1 B19 TMH1 C5 SANS 3001-GR10:2009 SANS 1243	2.3 3.2.5 4.2.2(ii) 4.2.5(viii) 2.4 4.2.3(iii)

(i) Average Least Dimension (ALD) (SANS3001-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 6.

4.4.2 Slurries and Microsurfacing

Bituminous slurries and micro-surfacings basically comprise a mixture of finely 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 8, 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 6.

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 0, Section 4.2.3.
COLTO requires an Immersion Index test on briquettes made with the slurry aggregate and 80/100 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, Section 9. This section includes tests carried out on the existing road surface, such as texture depth and ball penetration. 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 sand 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 4.

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 308
- Invert bitumen emulsion: SANS 1260

Should primes be used that do not comply with SANS specifications, typically proprietary products, the supplier should provide specifications against which the product can be tested 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 MC30.

Table 9. 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%[2]	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[1]	TMH1 B11 (Riedel & Weber)	Section 4.1.6(iii)

Notes:

1. This test should be carried out to assess the effectiveness of precoating on the aggregate and binder to be used on a particular project. Tests should therefore be carried out with the aggregate with and without precoating.
2. v/v% = volume/volume expressed as a percent

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 9.

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, Section 7.3.4.

4.6 Tests on Bitumen Stabilised Materials (BSMs)

Bitumen stabilised materials are materials treated with foamed bitumen or bitumen emulsion. The materials are typically used for base layers and occasionally subbases. BSMs are divided into three classes, BSM 1, 2 and 3, in TG2, 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, stabilised 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.

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 (2000).

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.

Figure 33. Indirect Tensile Test (ITS)

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.

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

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 and 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 (Test Protocol)

The triaxial test 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 34. 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 35. 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.

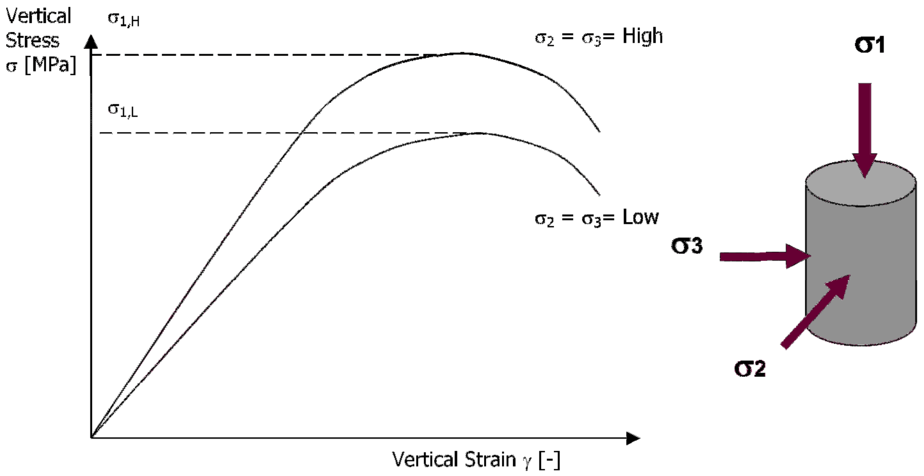


Figure 34. Monotonic Triaxial Tests on Granular Material

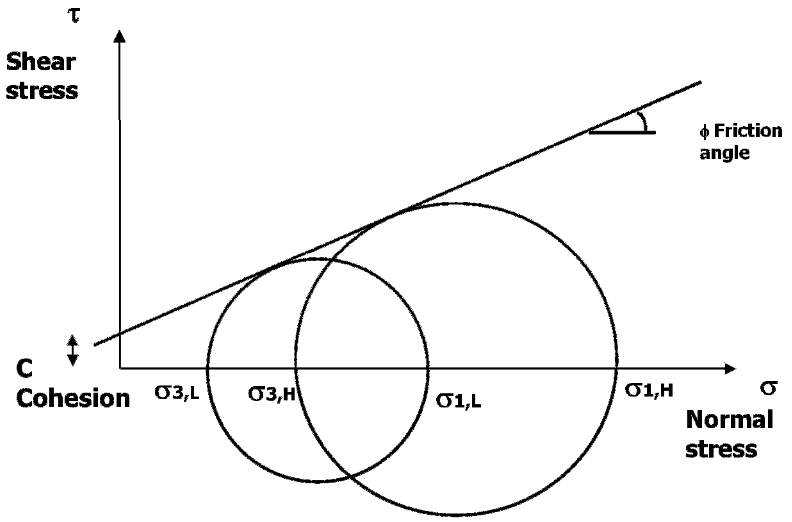


Figure 35. Mohr Coulomb Plots of Monotonic Triaxial Test Results

Triaxial testing is not currently widely used. However, it is likely to become a standard test for granular and stabilised 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 36 shows a typical triaxial test, in which specimens 150 mm in diameter and 300 mm in height are tested.

Figure 36. Triaxial Test

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.
- **Stabilisation** 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 the case of 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.

Table 10. 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 coarse aggregates	SANS 5841 [SANS 3001-AG10]	3.2.5
FACT value (10% fines aggregate crushing value) of coarse aggregates	SANS 5842 [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 (BRD), apparent relative density (ARD) and water absorption of aggregate retained on the 5 (4.75) mm sieve	TMH1: B14 [SANS 3001-AG20 & AG21] [1]	
Determination of the dry bulk density (BRD), apparent relative density (ARD) and water absorption of material passing the 5 (4.75) mm sieve	TMH1: B15 [SANS 3001-AG20 & AG21]	
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 5836:2007	
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	

Note:

1. TMH method will be superseded by SANS method.

5.1.1 Tests on Aggregates used in Concrete

As listed in Table 10, 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 the 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 11.

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 (Fulton, 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 12. 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.

Table 11. 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
The determination of the Aggregate Crushing Value	TMH1: B1 (SANS 3001-AG10)	Compressive strength and abrasion resistance of concrete
The determination of the 10% Fines Aggregate Crushing Value (10% FACT)	TMH1: B2 (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 12. 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 1008:2002 "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

Water in Sugarcane Areas

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

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 and tests for the presence of sugar should be undertaken in these cases.

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 concrete as well as 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 previous, 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, such as the formwork itself, impervious sheeting, and keeping the concrete work damp using water sprays.

In some cases, and certainly in the case of 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 C 309, 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 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 13. 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 13. Tests Carried out on Fresh Concrete

Description of Concrete Tests	Test Method	Section Reference
Density of compacted freshly mixed concrete	SANS 6250 (SANS 3001-CO20)[1]	
Air content of freshly mixed concrete: Pressure method	SANS 6252 (SANS 3001-CO22)[1]	
Dimensions, tolerances and uses of cast test specimens	SANS 5860 (SANS 3001-CO10) [1]	
Mixing fresh concrete in the laboratory	SANS 5861-1 [SANS 3001-CO1][2]	
Sampling of freshly mixed concrete	SANS 5861-2 [SANS 3001-CO1][2]	
Making and curing of test specimens	SANS 5861-3 [SANS 3001-CO1][2]	
Consistence of freshly mixed concrete: **Slump test**	SANS 5862-1 [SANS 2001-CO2] [2]	5.1.8.1
Consistence of freshly mixed concrete: **Flow test**	SANS 5862-2:2006 (SANS 3001-CO3)[1]	
Consistence of freshly mixed concrete: **Bleeding test**	ASTM C232-92	5.1.8.1
Consistence of freshly mixed concrete: **Vebe test**	SANS 5862-3:2006 (SANS 3001-CO4)[1]	
Consistence of freshly mixed concrete: **Compacting factor and compaction index**	SANS 5862-4:2006 (SANS 3001-CO5)[1]	

Notes:
1. Method numbers in (parenthesis) are likely renumbering for inclusion in SANS 3001 series.
2. Test method to be superseded by method in [parenthesis].

(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 slip-form paving methods. The compaction factor test is also used in fairly rare instances to assess the workability of concrete mixes.

(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.

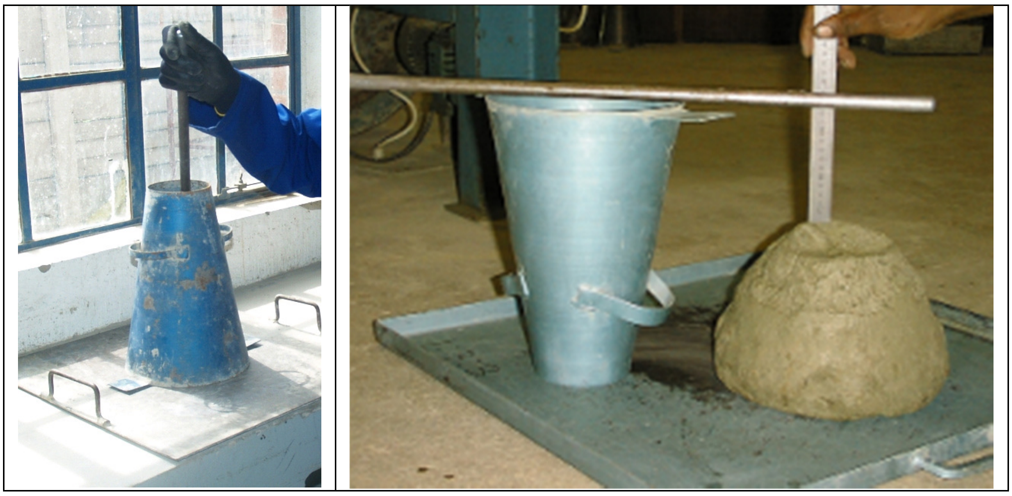


Figure 37. Slump Test

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 to reduce concrete strengths and air content tests are necessary to monitor this property using SANS 6252:2006.

5.1.8.2 Tests on Hardened Concrete

Tests carried out on hardened concrete are listed in Table 14. 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 of cube specimens are covered in Table 14 while the method for crushing the cubes to obtain compressive strength is included in Table 14, and the test is illustrated in Figure 38The tensile splitting strength test (SANS 6253:2006) is used much less.

The **flexural** strength of hardened concrete (SANS 5864:2006) 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".

There are occasions when the measurement of concrete strength is determined by testing **cores** extracted from in situ concrete, such as when the cube results are below the required strength. The method described in SANS 5865:2006 should be followed, with the interpretation of the results being carried out in accordance with Section 14.4.3 of SANS 10100-2:1992.

Table 14. Tests Carried out on Hardened Concrete

Description	Test Method	Section Reference
Compressive strength of hardened concrete	SANS 5863 (SANS 3001-CO11)	5.1.8.2
Flexural strength of hardened concrete	SANS 5864 (SANS 3001-CO12)	5.1.8.2
Drilling, preparation, and testing for compressive strength of **cores** taken from hardened concrete	SANS 5865 (SANS 3001-CO6)	
Density of hardened concrete	SANS 6251 (SANS 3001-CO21)	
Tensile splitting strength of hardened concrete	SANS 6253 (SANS 3001-CO13)	
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	Explained below SANS 1010092, Section 15.2.3	5.1.8.2
Shrinkage Tests	SANS 6085	5.1.8.2
Alkali-silica reactivity	SANS 6245, COLTO?	5.1.8.2

Note:
Method numbers given in brackets are likely renumbering of methods in the SANS 3001 suite.

Figure 38. Compressive Strength Test

(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 used 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 6245:2006. COLTO also contains 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 (1987)
- Concrete Manufacturer's Association publications on block paving (CMA, 2009)
- COLTO

Typical concrete blocks are shown in Figure 39.

The following sections list the tests required on concrete blocks and bedding and jointing sand, which are summarised in Table 15.

Figure 39. Concrete Blocks

Table 15. 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

The 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 1058:2009 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 1058:2009.

5.2.2 Tests on Bedding and Jointing Sand

Bedding and jointing sand have separate specifications as regards their gradings. 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 2.4) 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 Stabilised Materials

Cementitiously stabilised materials consist essentially of crushed stone gravel that has been treated with cemetitious stabilising agent such as cement or hydrated lime, and used as a structural layer in a road pavement. In TRH14, the material classes for Cementiously Stabilised Materials are the C-classes: C1, C2, C3 and C4.

Table 16 summarises methods used to test cementitiously stabilised materials, such as those stabilised 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)

The test methods are currently being revised or formulated and are to be published by SABS during 2010 as part of the SANS 3001 series. The application of these test methods is discussed below.

Untreated Material Class

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

Table 16. Tests for Cementitious Stabilising Materials

Description	Test	Chapter Reference
Initial consumption of lime/stabiliser	Appendix A, Method A.1 SANS 3001-GR57[2]	5.3.1(i)
Maximum dry density and optimum moisture content of laboratory mixed cementitiously stabilised materials	SANS 3001-GR31:2010[1]	5.3.1(ii)
Preparation, compaction, and curing of specimens of laboratory mixed cementitiously stabilised materials	SANS 3001-GR50:2010[1]	5.3.1(iii)
Sampling, preparation, compaction and curing of field mixed freshly cementitiously stabilised materials including maximum dry density and optimum moisture content	SANS 3001-GR51:2010[1]	5.3.2(i)
Sampling and preparation of cored specimens of field compacted matured cementitiously stabilised material	SANS 3001 GR52:2010[1]	5.3.2(iv)
UCS (unconfined compressive strength)	SANS 3001 GR53:2010[1]	5.3.2(iii)
ITS (indirect tensile strength)	SANS 3001-GR54:2010[1]	5.3.2(iii)
Wet/dry brushing test	TMH1: Method A19 [SANS 3001-GR55][2]	5.3.1(v)
Acceleration carbonation test	Appendix A, Method A.2	5.3.1(vi)
CSIR erosion test	CSIR	5.3.1(vii)
Strength loss versus mixing time	Appendix A, Method A.3	5.3.1(viii)
Degree of compaction	TMH 1 A10(a) and A10(b) [SANS 3001-NG1 to NG5][3]	2.6 5.3.2(i)
Stabiliser content	TMH1-A15d	5.3.2(ii)

Notes:
1. Tests are due to be published by SANS in 2010.
2. Currently being revised by SANS.
3. TMH1 methods will be superceded by SANS methods.

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 stabilisation tests should be carried out.

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

As different materials react differently with various stabilisers, it is important to ensure that the stabiliser 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 stabilisation. These are described in the following sections.

Suitability of Material to Stabilisation

When the ICL is less than 3.5% the material is likely to be suitable for stabilisation.

(i) Initial Consumption of Lime/Stabiliser, ICL/ICS (Appendix A)

The gravel ICL test should be carried out initially to determine the approximate content of stabiliser that will be required. The currently recommended method is included Appendix A, Method 1. The method is being drafted into a SANS method: SANS 3001-GR57 "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 ICL/ICS of that material.

The interpretation of the test using the pH versus stabiliser content curve can be problematic as there is seldom a definite point at which the pH stabilises. 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 stabilisation appears to be effective, feasible and economic, i.e., the ICL/ICS is not too high, not more than about 3.5%, proceed with further tests to establish the best stabiliser type and content to achieve the desired strength.

(ii) MDD and OMC of Stabilised Material (SANS 3100-GR 31)

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 stabiliser. This testing must use the same stabilisation product that is intended to be used during construction. See Section 2.5 for a discussion of the tests.

(iii) Preparation, Compaction, and Curing of Specimens of Laboratory Mixed Cementitiously Stabilised 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 40) and indirect tensile strength testing (Figure 33) is carried out as part of the mix design procedure to establish an appropriate stabilising 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 stabiliser contents. Test programs involving more than one stabilising 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 stabiliser types combined with 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.

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.

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.

Accelerated Curing

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

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 stabiliser combinations. Accelerated curing tends to overestimate the 7 day strength in most cases. It is recommended that correlation tests be done using the stabiliser and material from the project if accelerated curing is to be used on a project.

Figure 40. Unconfined Compressive Strength Test

(v) Wet/Dry Brushing Test (TMH1 Method A19, SANS 3001-GR55 and GR56)

To determine that the quantity of stabiliser added is adequate to ensure the long-term durability of the stabilised 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 41 assesses the effect of wetting and drying on the surface of stabilised 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 wet/dry durability test method is included in TMH 1 as an appendix to Method A19 as is currently being revised as SANS 3001-GR55 "Determining the wet/dry durability of compacted and cured specimens of stabilised graded materials". The test is carried out by brushing specimens after each wet/dry cycle by hand. 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 is likely to be SANS 3001-GR56.

Figure 41. Wet/Dry Brushing Test (Mechanised Brushing)

(vi) Accelerated Carbonation Test (Appendix A, Method A2)

To assess whether carbonation of the material will have a significant effect on the strength/durability of the stabilised material, the accelerated carbonation test should be carried out (Method A2 in Appendix A). This test involves subjecting a compacted specimen of the stabilised 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 stabilised 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 stabiliser 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.

Samples Made from Field Mix

During field sampling for control testing, the samples obtained after addition of the stabiliser 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.

(vii) CSIR Erosion Test

A useful test to determine the durability of stabilised materials is the CSIR erosion test, shown in Figure 42. The test involves the wheel tracking of beams of stabilised materials under water and with a grit covered rubber membrane between the sample 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) stabilisation.

Figure 42. Erosion Test

(viii) Strength Loss versus Mixing Time (Appendix A, Method A.3)

Problems have been encountered where the actual site working time of the stabilised 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 3 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 stabilisation work.

5.3.2 Field Control Tests

During construction, a number of tests are required; these include:

(i) Degree of Compaction

The degree of compaction is normally controlled using nuclear or sand replacement methods to determine the field densities as specified in TMH 1 A10(a) and A10(b) (to be replaced by SANS 3001-NG1 to NG5; see Section 2.6). To establish the degree of compaction, the field densities are compared with the MDD determined in SANS 3001GR51. 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 stabiliser content or by using the freshly stabilised 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 2.6 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).** 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) is the most commonly used. These methods are generally based on determining the calcium oxide content of the stabilised 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 stabiliser, which is measured in most of the tests. Where materials with high and/or variable calcium oxide contents are stabilised, the accuracy of the results is thus impaired.

Probably the best way of checking the stabiliser content of the treated material is to physically check the amount of stabiliser added and the volume of material treated. This is relatively simple when bags of stabiliser are added but more complicated when the stabiliser is distributed from a bulk tanker. Mat or pan methods of collecting the applied stabiliser and weighing it are useful alternative methods. In these cases, more reliance has to be placed on physically checking that the correct quantity of stabilising agent is spread on the road, and that it is it 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 stabilised 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 (the new method SANS 3001-GR51 addresses this) and often results in a significant difference between design and field test results. 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 stabiliser to fine grained materials to achieve acceptable ITS values can result in UCS values exceeding the upper UCS limits. When good quality materials are stabilised, a low percentage passing the smaller sieve sizes can result in high UCS values. It is considered 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 stabiliser 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 UCS upper limit is exceeded.

(iv) Sampling and Preparation of Cored Specimens of Field Compacted Matured Cementitiously Stabilised Material (SANS 3001–GR 52)

The coring of a cementitiously stabilised pavement layer is not carried out routinely, but may be undertaken occasionally to obtain specimens for strength testing. Cementitiously stabilised 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 stabilisers are available for the improvement of materials that do not meet the standards required. Their effect on the local materials to be utilised needs to be confirmed prior to and during construction by routine laboratory testing and the quality of the constructed layer must be confirmed after construction.

6.1 Material Stabilisation Design

Currently no national standards for the composition or utilisation of non-traditional soil stabilisers 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 stabilisers (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, Section 13.1. 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 stabilisers, the specified material properties (Chapter 4, Section 6.2) should be identified and the material/stabiliser 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 17 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 17. Interim Guide to Use of Non-Conventional Stabilisers

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:

1. 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 stabilisers (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 "stabilise" the material in order 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 stabilisation" 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) stabilisation 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 the active clays (described above) and a cation exchange capacity of more

Certification of Proprietary Properties

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.

than 15 meq/100g, 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 stabilisation 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 18 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 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%.

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 following properties (Table 19).

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 18. 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

Snake-Oils

Proprietary products used for stabilisation 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.

Table 19. Material Characteristics of Sand and Black Clay Mix

Material	Characteristics						
	Max size (mm)	P0.425	P0.075	PI (%)	OMC (%)	MDD (kg/m^3)	CBR (%)
Sand	5 (4.75)	82	22	3	8.6	2071	42
Clay	5 (4.75)	80	55	35 – 40	18.2	1700	< 2
70:30 sand:clay	5 (4.75)	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

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