

TECHNICAL RECOMMENDATIONS
FOR HIGHWAYS

DRAFT TRH7: 1994

**THE USE OF
BITUMEN EMULSIONS IN THE
CONSTRUCTION AND
MAINTENANCE OF ROADS**

1994

ISBN 1-86844-150-4
DRAFT TRH7, pp 1-72 Pretoria, South Africa, 1994



Komitee van
Staatspadowerhede

Committee of State
Road Authorities

DRAFT TRH7: 1994

**THE USE OF BITUMEN
EMULSION IN THE
CONSTRUCTION AND
MAINTENANCE OF ROADS**

Compiled by

Committee of State Road Authorities

Funded by

South African Roads Board

Published by

Department of Transport

P O Box 415

PRETORIA

0001

Republic of South Africa

PUBLISHED 1972

REVISED 1994

PRINTED 1995

REPRINTED 1996

REPRINTED 1998

FOREWORD

These recommendations on the use of bitumen emulsions have been prepared under the guidance of a subcommittee of the Highway Materials Committee. This subcommittee is represented by various road authorities, Sabita and the CSIR.

The first edition of the TRH7: "The use of bitumen emulsions in the construction and maintenance of roads" was published in 1972. Since that period significant changes have occurred in the field of bitumen emulsions, in particular the use of polymer-modified emulsions.

The present TRH7 is a more comprehensive guidelines document reflecting current and proven practices regarding the use of both conventional and modified emulsions in a wide range of applications in the maintenance, rehabilitation and new construction of roads.

It is hoped that this document will contribute towards a better understanding of the use of bitumen emulsions and its wide ranging field of applications. These applications are well suited to the Reconstruction and Development Programme (RDP)

E M de Villiers

Chairman

HMC Subcommittee on the revision of the TRH7

PREFACE

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) are written for the practising engineer and describe current, recommended practice in selected aspects of highway engineering. The recommendations are based on South African experience and research and have the full support of the Committee of State Road Authorities (CSRA).

This document was produced by a subcommittee of the Highway Materials Committee and, to confirm its validity in practice, is circulated in draft form for a trial period before being submitted to the CSRA for final approval.

SYNOPSIS

Bitumen emulsion comprises of two immiscible materials, bitumen and water, blended by mechanical shearing in a colloid mill. The dispersed bitumen globules are held in suspension in water by an emulsifying agent.

Enhanced properties are achieved by using polymer modified emulsions.

This document commences with an overview of the composition, manufacture, behaviour and properties of both conventional and modified emulsions, followed by a discussion on test methods and current specifications. Guidelines on sampling, storage, handling and safety are also provided.

The main emphasis, however, is on the wide range of applications in maintenance, rehabilitation and new construction of roads. The following relevant aspects are covered: material selection, design procedures, construction guidelines and constraints pertaining to: emulsion treated bases; prime coats; curing membranes; tack coats; pre-coating of aggregates; surface treatments; cold-mixed asphalt; maintenance operations (e.g. patch repair, pothole repair and crack sealing) and rehabilitation (e.g. recycling and mulch treatment).

KEYWORDS

Bitumen emulsions, modified, polymer, manufacture, behaviour, testing, handling, storage, safety, seals, GEMS, slurries, cold-asphalt, maintenance, rehabilitation

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1. INTRODUCTION

1.1 BACKGROUND

Bitumen emulsions were first developed at the turn of this century, but it was only during the 1920s that they were used in their present form in road works. The growth in the use of bitumen emulsions was relatively slow at first on account of the limited number of types and grades available and of the lack of expertise in using them. After World War II there was a sharp increase in their use as a result of increased traffic loads and volumes.

The energy crisis in the early 1970s, which prompted many energy conservation measures world-wide, contributed to the increased use of bitumen emulsions in road construction. The early 1990s saw the large-scale implementation of polymer-modified emulsions in South Africa.

Among the benefits realised by the use of bitumen emulsions are reductions in energy and costs, since emulsions are applied at temperatures significantly lower than those required for bitumens, thus effecting savings in fuel consumption. In addition, as bitumen emulsions readily adhere to damp aggregates, the necessity for drying is eliminated, with consequent savings in both energy and time.

1.2 OBJECTIVES AND SCOPE

The objective of this manual is to provide guidelines for the use of bitumen emulsions in the construction and maintenance of roads. In the first part of the manual the focus is on the composition, manufacture, behaviour, handling and testing of bitumen emulsions. The second part contains guidelines for the application of bitumen emulsions in road works such as in surface treatments and bases.

This document is not intended to be used as a design document for seals, slurries or granular emulsion mixes, etc., but merely to provide guidelines for the selection and use of bitumen emulsion in these applications. The properties of bitumen emulsions and materials given in the document are not intended to be specifications, but are merely indications of desirable properties.

Bitumen emulsions are referred to simply as emulsions in the remainder of this document.

2. CHEMISTRY AND BEHAVIOUR OF EMULSIONS

2.1 GENERAL

An emulsion can be defined as follows:

"It is a heterogeneous system with two or more liquid phases, made up of a continuous liquid phase and at least a second liquid phase dispersed in the former as fine droplets."

2.1.1 Composition of bitumen emulsions

Bitumen emulsions are heterogeneous two-phase systems consisting mainly of two immiscible liquids: bitumen and water. The bitumen is dispersed throughout the continuous water phase in the form of discrete globules, typically 0,1 μm to 5 μm in diameter, which are held in suspension by electrostatic charges imparted by an emulsifier. The water is referred to as the dispersing phase and the bitumen as the dispersed phase.

There are two deviations from the above definition, namely invert emulsions and non-ionic emulsions. The invert emulsion is a type of emulsion in which the water is suspended in a finely dispersed state in bitumen. A non-ionic emulsion is a type of emulsion in which the suspended bitumen particles have no electrical charge.

Bitumen emulsions, therefore, consist of three or more basic components, namely:

- bitumen;
- water;
- emulsifying agents; and
- fluxing agents (optional).

The types of emulsifying agents can be classified as:

- anionic emulsifiers;
- cationic emulsifiers; or
- non-ionic emulsifiers (e.g. prime coats).

2.1.2 Classification

Emulsions are classified according to three criteria, namely:

- type of emulsifying agent (anionic or cationic);
- application (spray grade, pre-mix grade or stable-mix grade); and
- amount of residual binder (e.g. 60 per cent bitumen).

The types of emulsion in terms of their application are as follows:

- *Spray grade*: This type of emulsion is characterized by rapid breaking of the emulsion on application. It is normally used for seals.
- *Pre-mix grade*: This type of emulsion has sufficient stability to allow mixing with aggregate of 3 mm in size and larger before breaking of the emulsion occurs.
- *Stable-mix grade*: This type of emulsion has sufficient mechanical and chemical stability for all purposes involving mixing with stone chippings, natural gravels or soils (including aggregates containing large proportions of fines or chemically active materials such as cement or lime).
- *Special grades*: These are purpose-made emulsions for specific applications.

2.1.3 Modified emulsions

Whenever the traffic volumes, deflection bowl or crack activity characteristics of the pavement structure as well as environmental conditions do not permit the use of conventional emulsions, the bitumen or emulsion may be modified using polymers. Various polymers have been used in emulsions, with primarily the following being favoured:

- Styrene-butadiene Rubber (SBR);
- Styrene-butadiene-styrene (SBS); and
- Ethylene-vinyl-acetate (EVA).

At present latex (SBR) modified emulsion is the type of modified emulsion which is most widely used in South Africa. It generally consists of a spray grade cationic (65% or 70%) bitumen emulsion with a B8 (80/100 Pen) base bitumen. The latex used in the emulsion normally has a percentage solids (SBR) content in the range of 60 to 65 per cent by mass.

2.1.4 Method of specification

The properties of emulsions and of the recovered binder can be specified by any one of the following:

- Applicable SABS specifications;
- Sabita specifications;
- Specifications of road authorities; or
- Specifications of manufacturers.

NOTE: ALWAYS REFER TO THE LATEST SPECIFICATIONS. THIS DOCUMENT IS NOT A SPECIFICATION DOCUMENT FOR EMULSIONS AND RECOVERED BINDERS. THE VALUES PROVIDED IN THIS DOCUMENT WERE VALID AT THE DATE OF PUBLICATION.

Anionic emulsions:

The anionic emulsions available in South Africa are specified by the South African Bureau of Standards (Specification SABS 309⁽¹⁾). The latest revision of the specifications may be referred to for details.

The grades of anionic emulsions currently available are given in Table 2.1.

Table 2.1: Grades of anionic emulsions

Type of emulsion	Residual bitumen content (%)
Spray grade	60
	65
Pre-mix grade	60
Stable grade	60

Cationic emulsions:

The cationic emulsions available in South Africa are specified by the South African Bureau of Standards (Specification SABS 548⁽²⁾). The latest revision of the specifications may be referred to for details.

The grades of cationic emulsions currently available are given in Table 2.2.

Table 2.2: Grades of cationic emulsions

Type of emulsion	Residual bitumen content (%)
Spray grade	60
	65
	70
Pre-mix grade	60
	65
Stable grade	60

Modified emulsions:

At present only SBR and SBS are used in the production of modified cationic emulsions using two grades of bitumens, namely B4 and B8 viscosity grades.

In the case of modified emulsions, the appropriate specifications provided by the road authorities, Sabita or the manufacturers apply. The specifications for various types of modified emulsion may differ, depending on their use.

2.1.5 Factors affecting emulsions

Many factors related to the composition of emulsions affect their production, storage, use and performance, including:

- chemical and physical properties of the base bitumen;
- quantity and grade of the base bitumen;
- bitumen particle size in the emulsion;
- type and concentration of the emulsifying agent;
- manufacturing conditions;
- the ionic charge on the emulsion particle;
- the order of addition of the ingredients;
- the type of manufacturing equipment;
- properties of the emulsifying agent; and
- properties of modifiers.

2.2 EMULSION INGREDIENTS

Examination of the ingredients of emulsions is essential to enable one to understand how they work.

2.2.1 Bitumen

Bitumen is the basic ingredient of emulsions and comprises 60 to 70 per cent of the emulsion. Various grades of bitumen can be used in the manufacture of emulsions, the standard grades being B12 (60/70 Pen), B8 (80/100 Pen) or B4

(150/200 Pen). When the grade of the base bitumen in the emulsion is specified, the following factors should be taken into consideration:

- expected weather conditions at the time of application;
- the intensity and type of traffic loads;
- the general climatic conditions; and
- type of application.

When high temperatures prevail, base bitumens with high viscosities (at the time of construction or during in-service conditions) are preferred. At lower temperatures, base bitumens with low viscosities are preferred. Under heavy traffic conditions it has been found that emulsions made with high-viscosity base bitumens perform better than those made with low-viscosity bitumens. The selection of the appropriate emulsion (including the correct choice of base bitumen) is discussed in more detail in the sections on the applications of emulsions (e.g. emulsion-treated bases, seals, primes, etc.)

Different grades of bitumen should be used for different applications. For example, in the case of spray grade emulsions, consideration should be given to the cohesion (internal shear strength) and adhesion (bonding capacity) of the base bitumen.

In some cases cut-back bitumen may be used as the base binder, for example in the manufacturing of storage-stable mixes.

2.2.2 Water

Water is the second largest component of emulsions. It is important that the selected water contain minimal amounts of mineral and organic impurities.

Water found in nature, such as in boreholes, may be unsuitable due to impurities. Of particular concern, however, is the presence of positive or negative ions. In fact, magnesium and calcium ions could react on some types of emulsifiers to form compounds which are insoluble in water and which no longer have emulsifying properties.

Whenever emulsion is to be diluted in the field, the emulsion supplier should be consulted in order to assess the compatibility of the emulsion with the water on site and/or the appropriateness of the formulation being provided.

2.2.3 Emulsifying agents

The purpose of an emulsifying agent or emulsifier is to keep the bitumen globules in suspension. The electrical charge of the emulsifying agent determines whether the bitumen emulsion is cationic or anionic whereas the chemical type and concentration of the emulsifiers influence the stability of the bitumen emulsion (spray, pre-mix or stable grade).

Emulsifiers must be chemically activated before they can function. When activated, emulsifiers are molecules that consist of two different parts, namely:

- an electrically charged functional group (anionic or cationic), and
- a long hydrocarbon chain (R').

The type of bitumen emulsion (anionic or cationic) is determined by the electrical charge of the functional groups. Cationic functional groups are positively charged and anionic groups are negatively charged.

The hydrocarbon chain has an affinity to bitumen, but not to water (hydrophobic), whereas the ionic functional group has an affinity to water (hydrophilic), but not to bitumen.

During the manufacturing process the emulsifier orientates in such a way that the hydrocarbon chain penetrates the bitumen globule while the functional group is held on the surface of the bitumen globule.

Figure 2.1 illustrates how cationic emulsifiers attach to a bitumen globule. The hydrocarbon chain (R') has penetrated into the bitumen whereas the positively charged cationic functional group (NH_3^+) is held on the surface of the bitumen globule. When the emulsifier is initially activated, chloride ions (Cl^-) are formed and these ions remain in the water. The positively charged cationic groups of the emulsifiers attract these negatively charged chloride ions (Cl^-) to form a so-called "electrical double layer". It is these electrical forces that keep the bitumen globules in suspension.

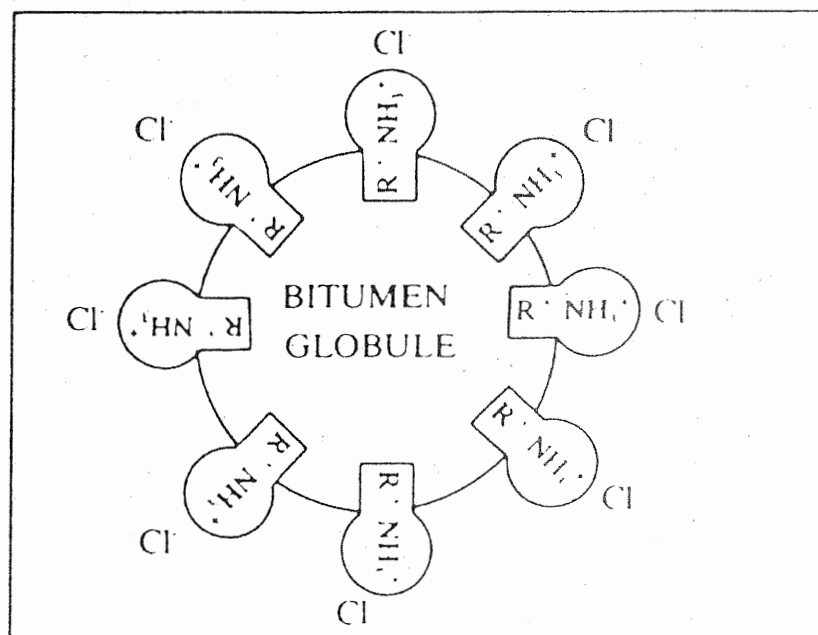


Figure 2.1: Cationic emulsifiers attaching to a bitumen globule.

A corresponding process occurs when anionic emulsifiers attach to a bitumen globule. The negatively charged anionic functional group (COO^-) is then held on the surface of the bitumen globule and it attracts positively charged ions (Na^+ or K^+) to form an "electrical double layer".

2.2.4 Polymers

There is a growing trend towards modification of base bitumens by means of polymers. Currently SBR-modified emulsions are used on a large scale in South Africa. However, there is an increasing use of SBS- and EVA-modified emulsions worldwide. Emulsions made with polymer-modified base bitumens can be used in conditions such as in extreme temperatures and/or under high traffic, where conventional emulsions have reached their functional limits.

Polymer-modified emulsions have the following characteristics by comparison with conventional emulsions:

- improved adhesion to aggregates;
- improved cohesion of the base binder;
- decreased sensitivity to environmental conditions (e.g. reduced temperature susceptibility);
- lower fluxing rates (which allow faster curing rates);
- improved wetting of aggregates by permitting a thicker binder film; and
- improved resistance to bleeding.

2.3 PRODUCTION OF EMULSIONS

Bitumen emulsions are made by mechanically dispersing the base bitumen (conventional, cut-back or modified) in a liquid form in water which has been pre-treated with an emulsifying agent.

2.3.1 Equipment

The equipment required to manufacture the emulsion is a high-speed, high-shear mechanical mill (normally a colloid mill) which is used to divide the bitumen into tiny droplets. This mill has a high-speed motor which revolves at 1 000 to 6 000 rpm with a mill-clearance setting in the range of 0,25 to 0,50 mm. Such settings produce emulsions with bitumen droplets ranging from 1 μm to 10 μm in diameter.

Other equipment includes pumps, control valves, heat exchangers and meters for both the bitumen and the emulsified water.

2.3.2 Emulsifying process

During the emulsifying process concurrent streams of hot bitumen and water (which has been pre-treated with an emulsifying agent) are directed by pumps to the intake of the colloid mill. The bitumen and emulsifying water are subjected to intensive shear stresses as they pass through the mill. The newly-formed emulsion may then be pumped through a heat exchanger which is also used to raise the temperature of the incoming emulsified water just before it reaches the mill. From the heat exchanger the emulsion is then pumped into bulk storage.

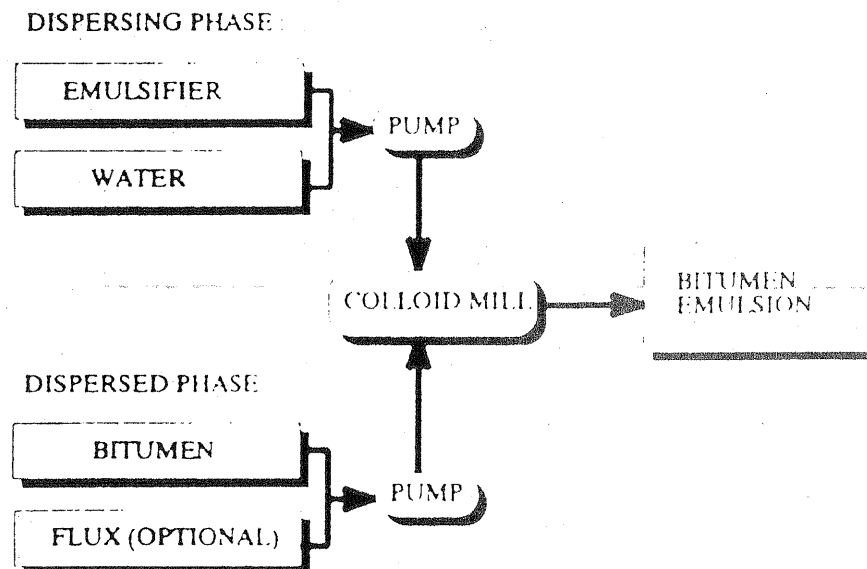


Figure 2.2: Diagram of the emulsion manufacturing process (anionic and cationic emulsions).

2.3.3 Modification of emulsion

The emulsion can be modified by either of two methods:

- *Modification of emulsions:* During this process the modifier is mixed with the premanufactured emulsion. It is generally used with modifiers such as SBR, and can be mixed on site, although from a control point this is not recommended.
- *Modification of the base bitumen:* During this process the base bitumen is modified prior to the emulsifying process. It is generally used with modifiers such as EVA and SBS, although SBR modifiers may also be used.

2.4 BREAKING AND CURING BEHAVIOUR OF EMULSIONS

2.4.1 Breaking

Breaking is the transition from emulsified binder to a solid binder. This process is essential for the bitumen emulsion to perform its functions of waterproofing and cementing.

Flocculation is the first stage during the breaking process and occurs when the dispersed binder globules agglomerate into clumps called flocs. During the process of coalescence the flocs stick together to form ever larger globules until a continuous mass of binder is produced.

Breaking of emulsions in normal use is essentially caused by the evaporation of the water phase. In many cases the electrical charge on the binder particles can react with the opposite electrical surface charge of many aggregates thereby contributing to the breaking process.

Figure 2.3 illustrates the processes of flocculation and coalescence.

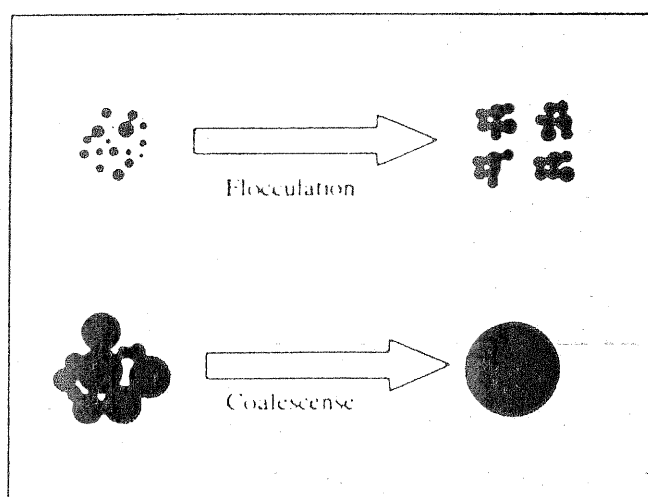


Figure 2.3: The process of flocculation and coalescence.

In the case of seals and other surface treatments, emulsions are formulated in order to break easily on contact with the aggregate or pavement surface (e.g. rapid-setting emulsions). The emulsions used in Granular Emulsion Mixes (GEMS), on the other hand, require more time to allow for the construction processes. Emulsions to be used for this purpose are formulated to break more slowly (e.g. slow-setting emulsions).

Some factors which affect the rate of breaking of bitumen emulsion are:

- the water content of the aggregate prior to mixing;
- weather conditions during application (temperature, humidity, wind, shade);
- grading of the aggregate in the mix;
- the porosity of the aggregate;
- voids content of the mix;
- type, residual binder content and quality of the emulsion;
- mechanical forces caused by compaction and traffic;
- mineral composition of the aggregate (the rate of curing is affected by possible physio-chemical interactions between the emulsion and the surface of the aggregate); and
- the magnitude of the electrical charge of the aggregate in relation to that of the emulsion.

2.4.2 Curing

After the emulsion has broken, the bitumen will adhere to the aggregate and gravel but will remain in a "soft" condition called the cheesy state. Curing denotes the transition from a soft residual binder with water present to final hardness when all water has evaporated. During the cheesy state, the binder exhibits a consistency like that of cheese and has poor stone retention properties.

In surface treatments the emulsion can take up to 48 hours to cure completely, or even longer if adverse weather conditions prevail. In the case of emulsion-treated bases (especially those made with substandard materials) this period may be significantly longer as the development of the adhesion characteristics of the emulsions in the mix depends on the evaporation of water. During this curing process, a significant increase in strength (normally reflected by the stiffness of the base) occurs over a period of up to two years. The length of the curing period is mainly affected by the climatic region, long curing times being associated with wet regions and colder climates.

The addition of cementitious binder where appropriate will facilitate a reduction in curing time.

2.5 BASIC PROPERTIES OF EMULSIONS

Emulsion properties can be divided into two groups:

- *Intrinsic properties* are those properties which are not dependent on the mineral products with which they are used. These properties include viscosity and storage stability.
- *Extrinsic properties* are those properties which are related to the behaviour of emulsions in the field, such as adhesion and rate of breaking.

Some of the relevant properties are discussed below.

2.5.1 Cohesion

Cohesion reflects the shear strength of the bitumen. It depends on several factors, of which viscosity is the most important. Cohesion has an optimum value corresponding to a given viscosity range. At low temperatures the binder becomes brittle under mechanical action. On the other hand, if the temperature exceeds a certain level the binder becomes fluid and is too soft to resist traction forces.

To improve the temperature-sensitive nature of an emulsion, especially in combination with heavy traffic, the cohesion of the base bitumen can be modified by the addition of polymers.

2.5.2 Adhesion

Adhesion reflects the bonding capacity or the degree to which the base bitumen bonds to the aggregate. A large number of factors affect adhesion, such as the specific relationship between the binder and aggregate, temperature and viscosity during setting, ambient humidity and water content of the aggregate, the texture of the aggregate and finally the presence of any disruptive materials, such as dust (in the case of seals).

Adhesion is satisfactory only if two conditions are met:

- The binder should be in contact with all the material involved, especially chippings. The process by which the aggregate is coated is referred to as *active adhesion*.
- Once the first condition has been satisfied, the bitumen and the aggregate which are bonded together should not separate under in-service conditions, especially in the presence of water. This second bonding process is referred to as *passive adhesion*.

The type of aggregate in combination with the ionic nature of the emulsion has an effect on the adhesion properties. These relationships can be theoretically explained as follows:

- In the presence of electropositive materials (e.g. dolerites and basalts):
 - there is a neutralizing reaction between these aggregates and *cationic* emulsified bitumen particles;
 - there is an attraction reaction between these aggregates and *anionic* emulsified bitumen particles.
- In the presence of electronegative materials (e.g. quartzites and granites):
 - there is an attraction reaction between these aggregates and *cationic* emulsified bitumen particles;
 - there is no reaction between these aggregates and *anionic* emulsified bitumen particles.

Therefore, when emulsions are used in an application where high adhesion of the bitumen directly to the aggregate is required, e.g. in the case of seals (using spray grade emulsions), electronegative "acidic" geological types of aggregate should preferably not be used with anionic spray grade emulsions. Using these materials, the breaking process is completely dependent on only evaporation of the water. The types of aggregate include:

- Quartzite
- Granite
- Sandstone
- Tillite
- Rhyolite and
- Amphibolite.

The ionic (anionic or cationic) nature of stable grade emulsion is less significant when used in granular mixes and slurries than that of spray grade emulsions (mainly due to the effect of the fines). Anionic stable grade emulsions are generally preferred as they are more workable than cationic stable grade emulsions, but due to the rising costs and short supply of certain agents, there is a move towards using cationic stable grade emulsions.

2.5.3 Viscosity

The viscosity of a bitumen emulsion is a measure of its ability to flow which is affected by the following factors:

- concentration of emulsion (amount of residual binder);
- type of dispersed phase (type of binder particles);
- nature of the dispersing phase;
- particle size distribution; and
- temperature of the emulsion.

The viscosity of emulsion is measured by means of the Saybolt-Furol apparatus.

Spray grade emulsions are designed to be sprayed through the spray-bar and nozzles of conventional bulk-binder distributors.

2.5.4 Storage stability

Bitumen emulsions are unstable liquid dispersions. This instability is the result of the tendency of emulsions to minimize the electrical surface forces of the emulsifiers over time. The final stage of this process is the separation of the emulsion components into two separated phases, namely water and binder.

During the normal breaking process, the concentration of the bitumen globules is increased mainly due to the evaporation of water. In the case of instability during storage the concentration of the bitumen globules is caused by sedimentation. During this process of sedimentation, the binder globules collect in the lower part of the container. The rate of sedimentation is governed by Stokes' Law.

This is followed by flocculation of the binder globules. This is a reversible situation as each binder globule is still protected by a thin film of surfactant. Finally, coalescence occurs when the binder flocs combine as a result of the breakdown of the protective emulsifiers. For all practical purposes this final process is irreversible.

The main factor determining storage stability is the size of the bitumen particles, which depends on factors such as the type of binder, type and quantity of emulsifiers and the manufacturing process.

3. STORAGE, HANDLING AND APPLICATION OF EMULSIONS

3.1 INTRODUCTION

Emulsions are more complex than conventional bitumen products and therefore require more precautions during storage and handling. The guidelines and safeguards prepared by the Asphalt Institute⁽³⁾ are intended for those with little or no experience in the use of emulsions and are given below.

Improper handling or storage of emulsions may cause premature breaking, thereby making them useless. Failure to follow even one of the precautions given below may cause the emulsion to be unsuitable at the time of use. Adherence to these few simple rules will save time and money, as the emulsion will be ready for use whenever required.

3.2 STORAGE

Guidelines on the storage of emulsion are given below:

- The emulsion should be stored in the same manner as water, namely between 10°C and 60°C, depending on use.
- Hot water should be used as the heating medium for storage tanks with heating coils. Low pressure waste steam may also be used, but the temperature on the coil surface should not exceed 85°C.
- The emulsion should be stored at the temperature specified for that particular grade (see Table 3.1). Spray grade emulsions can generally be stored at higher temperatures than pre-mix grade emulsions.
- The emulsion should not be heated above 85°C. Temperatures higher than this may cause the water to evaporate, with a resulting increase in viscosity and may cause a layer of bitumen to form in the tank. Emulsions with such increased viscosities can then no longer be used as intended. It will also be difficult to empty the tank.
- Emulsion should not be allowed to freeze. Freezing causes the emulsion to break and causes the separation of the bitumen and water, which then form two separate layers in the storage tank. The emulsion is then unsuitable for any use. The tank will also be difficult to clean.
- The temperature of the heating surface should not exceed 100°C. Temperatures in excess of this will cause premature breaking of the emulsion on the heating surface.

- Forced air should not be used to agitate the emulsion, as it may cause the emulsion to break.
- Storage facilities should be insulated for protection against freezing and for the best utilization of heat.
- Tall vertical storage tanks are preferable to horizontal tanks as they expose the least amount of the surface area of the emulsion to air. If emulsion is exposed to air, a skin of bitumen can form on its surface. When horizontal tanks are used, the formation of a skin of bitumen can be reduced by keeping the horizontal tank full in order to minimize the area of the emulsion exposed to air.
- Propellers located about one metre up from the tank bottom may be used to prevent the formation of surface skin. Large diameter, slow-turning propellers are preferred and should be used to roll the emulsion over, but overmixing should be avoided. If propellers are not available, the emulsion may be circulated from top to bottom of the tanks by means of pumps.
- In tanks which are not equipped with propellers, or a circulating system, a very light film of kerosene or oil on the surface of the emulsion can reduce skin formation.
- Cathodic protection should be provided to avoid possible corrosion of tank walls and heating coils.

Table 3.1: Storage temperatures for emulsions

Grade of emulsion (including SBR modified)	Maximum storage temperature (°C)	
	Over 24 hrs	Up to 24 hrs
60% bitumen	Air temp	60
65% bitumen	Air temp	60
70% bitumen	Air temp	60

3.3 GENERAL HANDLING

Guidelines for general handling of emulsion are given below:

- When emulsions are handled, they should be agitated gently to eliminate or reduce skin formation.
- Lines should be blown out and drain plugs should be left open when they are not in service.

- Pumps with proper clearances for handling emulsions should be used. Tightly fitting pumps can cause binding and seizing.
- Mild heating methods should be used to apply heat to the pump packing or casing to free a seized pump. Propane torches should be used with great care.
- Excess heat should not be applied to the packing glands or casings of pumps. The pump may be damaged and the bitumen may become oxidized.
- The pump should be warmed to about 65°C to facilitate start-up.
- When a pump has been out of service for even a short time, it should be primed with the appropriate type of oil in order to ensure a free start-up.
- When emulsions are diluted, the compatibility of water with the emulsion should be checked by testing a small quantity.
- If possible, warm water should be used for diluting. Water should always be added slowly to the emulsion.
- Repeated pumping and recirculation should be avoided if possible, as the viscosity may drop and air may become entrained, causing the emulsion to be unstable.
- Care should be taken to avoid the mixing of different types or grades of emulsions in storage tanks, transport vehicles or distributors. For example, if cationic and anionic emulsions are mixed, the blend will break and separate into water and coagulated bitumen which will be difficult to remove. Since it is hard to determine visually the difference between various emulsions, samples of the newly-delivered emulsion and of the stored emulsion should always be taken and checked for compatibility.
- In order to prevent foaming, inlet pipes and return lines should be placed at the bottom of tanks.
- In order to minimize contamination from skinning which may have formed, the emulsion should be pumped from the bottom of the tank.
- It should always be borne in mind that emulsions with the same grade designation can differ greatly in their chemistry and in their performance.
- Emulsions should be transported in truck haulers fitted with baffle plates in order to prevent sloshing.

- Emulsions which have been stored for prolonged periods should be mixed by circulation or any other suitable means.
- Tight-fitting pumps should not be used for pumping emulsion as they may "freeze".
- Rapid-setting grades of emulsions should not be diluted with water. Medium- and slow-setting grades may be diluted in this way.
- Emulsions should not be recirculated for long periods. They tend to lose viscosity when subjected to pumping. Air bubbles may also become entrained which could render the emulsion unstable.
- Emulsions should not be loaded into storage tanks, transport vehicles or distributors containing remnants of incompatible materials (see Table 3.2).

Table 3.2: Guide for conditioning of emptied tanks before loading emulsions⁽⁴⁾

Last product in tank	Cationic Emulsion	Anionic Emulsion
Bitumen	A	A
Cutback bitumen	A	A
Cationic emulsion	-	B
Anionic emulsion	B	-
Crude oil	A	A
Any other product	C	C
A: Drain tank and flush with paraffin or diesel B: Flush out surplus product with water until water is clear and drain tank and lines. Flush out with paraffin or diesel. Flush out surplus paraffin or diesel with water and drain tank and lines. C: Tank must be cleaned.		

Possible causes of contamination of emulsions as well as some recommended precautions are given elsewhere⁽³⁾.

3.4 APPLICATIONS

Emulsions can be used for the construction of surface treatments, cold mix asphalt and emulsion-treated bases.

3.4.1 Surface treatments

The design of seals is discussed in TRH3⁽⁵⁾ and their construction is discussed in the CSRA⁽⁶⁾ specifications. However, aspects considered to be important are briefly discussed below.

Before emulsion is sprayed, the primed base or existing surface should be free of sand, dust, mud and fallen leaves.

Although emulsions may be used at ambient temperatures, the typical spray temperature and minimum road temperatures should be adhered to (see Table 3.3). This table merely provides an indication of typical values and the specified temperature should always be related to the viscosity requirements for spraying emulsions.

Table 3.3: Typical spray temperatures for emulsion and minimum road surface temperatures.

Type of emulsion (including SBR modified)	Heating and spraying temperature (°C)			Road temperature (°C)
	Min.	Max.	Recom.	Min.
60% bitumen	Air temp	60	60	10
65% bitumen	Air temp	60	60	10
70% bitumen	Air temp	60	60	10

The net cold residual binder application rates are converted to an emulsion application rate using the conversion factors provided in TRH3⁽⁵⁾. The range of the conversion factors is given in Table 3.4

Table 3.4: Suggested conversion factors for different emulsions for converting cold net residual binder to spray rates.

Type of emulsion	Conversion factor
60% residual bitumen content	1,67 to 1,70
65% residual bitumen content	1,55 to 1,57
70% residual bitumen content	1,44 to 1,46

Distributors should be checked at regular intervals to ensure that transverse variations in the functioning of the jets are within acceptable limits. National standards for the spraying performance of binder distributors and the requirements for acceptable functioning of bitumen distributors are given in TMH2⁽⁷⁾.

When a hand-held spray lance is used (either fed from a bulk distributor or from a hand-operated drum pump on a trolley) the best results will be obtained if the lance is moved in an even circular motion and kept at a constant height above the road surface.

Before emulsions are sprayed over a layer of stone, it is often advantageous to dampen the stone with a water tanker. This should not wet the stone excessively or form pools of standing water. This dampening delays the breaking process and, on a hot day, improves the penetration of emulsion into the stone mat. On no account should aggregate be precoated when using emulsion binders. The absorptive qualities of the aggregate facilitates curing.

Slurries can be prepared and applied as follows:

- *Self-propelled slurry machines:* These machines carry all the materials, feed them in controlled proportions to a mixer and discharge the resulting slurry to a spreader-box. The spreader box is dragged behind the machine and applies the slurry to the surface at a controlled thickness. The final surface texture can be improved by means of a burlap drag or by hand brooming.
- *Batch mixing:* Batch mixing is carried out in a transit or concrete mixer. The slurry is then spread on the surface by a drag spreader or by hand-held squeegee brooms.

3.4.2 Emulsion treated bases

In the case of Granular Emulsion Mixes (GEMS) there are two generally accepted methods of applying or mixing the emulsion with gravel or recycled material:

- *In diluted form:* in this case the emulsion is diluted with the compaction water, spread over the gravel and mixed according to the specified process.
- *In undiluted form:* in this case the emulsion is applied directly to the layer after the compaction water has been mixed with the gravel. It is then mixed into the gravel according to the specified process.

Under no circumstances should undiluted emulsion come into contact with dry aggregate. This results in the premature breaking of the emulsion, with consequences such as loss in strength of the GEMS.

3.5 SAFETY

The scope of this section does not include safety precautions at the production plant and is intended mainly for the user of emulsions.

3.5.1 Finished products

As bitumen emulsions are used at ambient temperatures or are slightly heated the main risk of handling bitumen, i.e. burns to the body or skin, is greatly reduced. However due to the presence of emulsifiers and additives in the emulsion it is advisable to adhere to the following recommendations:

- frequent and prolonged contact with the skin should be avoided;
- protective clothing and eye protection should be provided;
- clothes impregnated with the product should be removed immediately, and
- any parts of the body which have come into contact with the emulsion should be thoroughly washed with soap and water before the emulsion breaks.

3.5.2 Storage and handling

The temperature of emulsion when it leaves the production facility may be as high as 80°C. If the worksite is in close proximity to the manufacturing plant, the emulsion may still be at this high temperature upon arrival. All measures should be taken to avoid burns due to contact or splashing.

General handling of emulsion and repairs to equipment may involve skin contact. The use of oil insoluble barrier creams in these circumstances is suggested. However, it is stressed that barrier creams are not substitutes for protective clothing and gloves.

Guidelines on protective clothing are provided in the Sabita manual on safety⁽⁴⁾.

If emulsion is accidentally spilled or leaks onto the ground, breaking of the emulsion should be accelerated by the addition of sand or lime. The area of spillage should be cleaned after the emulsion has broken.

3.5.3 First aid procedures

If emulsion is ingested, the victim should not be made to vomit, but should be kept calm and a doctor should be called.

When emulsion comes into contact with the skin, the affected area should be washed thoroughly with cold water and soap. If possible, all emulsion should be removed before it breaks. If the emulsion breaks, only oils such as medicinal paraffin should be used to remove bitumen from the skin. Fuel (petrol), gasoil (diesel) or halogenated solvents should never be used as these may cause dermatitis. All contaminated clothing should be removed.

If large amounts of emulsion come into contact with the skin and allowed to break, the injured person should be referred for medical treatment.

If the emulsion comes into contact with the eyes, they should be rinsed immediately with large amounts of water for at least twenty minutes. Medical advice should be sought.

4. EMULSION SAMPLING, TESTING AND SPECIFICATIONS

4.1 BACKGROUND

The testing of emulsions should be in accordance with the standard SABS specifications for emulsions, namely SABS 309⁽¹⁾ for anionic emulsions and SABS 548⁽²⁾ for cationic emulsions. A summary of the tests required for emulsions as described in the SABS specifications is given in paragraph 4.3. In addition, extraction methods and methods of testing related to the base binders in both conventional and modified emulsions are described.

4.2 SAMPLING

The general procedure for sampling emulsions is described in ASTM D140⁽⁸⁾.

The supplier should provide the batch number on his supply invoice as well as the type of product, viscosity of the blend and percentage flux in the blend. The percentage flux in the blend should be indicated as it may influence the curing of the emulsion and consequently the timing of successive operations.

Sampling containers for emulsions should be wide-mouth jars or bottles made of plastic. Metal containers should not be used.

If possible, the emulsion should be sampled at the point of manufacture or storage. Otherwise, samples should be taken from the shipment immediately upon delivery.

The following precautions should be adhered to:

- The sample containers should be new. The container and its lid should fit together tightly.
- Care should be taken to prevent the samples from becoming contaminated. The sample container should not be submerged in solvent, nor should it be wiped with a cloth saturated with a solvent. Any residual material on the outside of the container should be wiped off with a clean, dry cloth immediately after the container is sealed.
- The container should be filled to the top to minimize the likelihood of breaking or separation.
- The sample should not be transferred into another container.
- The filled sample container should be sealed tightly immediately after the sample is taken.

- Samples of emulsions should be packaged and shipped in such a manner as to protect them from freezing.
- All samples should be packaged and shipped to the laboratory on the day they are taken. The containers, tightly sealed, should be packed in a shock-absorbent material in order to reduce the possibility of damage during shipment.

4.3 TESTS AND SPECIFICATIONS: CONVENTIONAL EMULSIONS

4.3.1 Tests on emulsion

The following properties of anionic emulsions should be determined (SABS 309⁽¹⁾):

- viscosity at 50°C (Saybolt Furol method);
- binder content;
- residue on sieving;
- sedimentation after 60 complete rotations;
- coagulation value when mixed with standard dolerite chippings; and
- coagulation value when mixed with portland cement.

The following properties of cationic emulsions should be determined (SABS 548⁽²⁾):

- viscosity at 50°C (Saybolt Furol method);
- binder content;
- fluxing agent content;
- particle charge (modified and standard);
- binder deposit on the cathode after 30 minutes;
- sedimentation after 60 complete rotations; and
- coagulation value when mixed with standard silica flour.

The tests to determine these properties are briefly described below:

Viscosity test: The viscosity of bitumen emulsions is measured by means of the Saybolt Furol Viscometer. In this test the time of efflux of a given volume of emulsion through a standard orifice is measured.

Binder content: A distillation procedure is carried out by means of the Dean and Stark apparatus. An organic liquid immiscible with water (toluene is usually used) is added to the sample and the flask is heated. The organic liquid distills into the receiving flask, carrying with it the water which then separates into a lower layer. The volume of the water is measured and, by difference, the residual binder content is determined.

Sieve test: A quantity of emulsion is poured through a very fine sieve. After being rinsed, the amount of bitumen in the form of large particles, strings or lumps retained on the sieve is determined. The bitumen particles of a good quality emulsion should be so small that virtually all pass through the mesh of the sieve.

Coagulation value test: A quantity of emulsion is mixed with either dolerite stone chippings or cement. In the case of spray grade emulsions, the emulsion should break and coat the chips. In the case of pre-mix and stable-mix grade emulsions, the emulsion should not break when mixed with cement.

Sedimentation test: A sample of emulsion is placed in a jar which is centrifuged at a specified speed. After the centrifuge has stopped it should be easy to mix the emulsion back to its original quality. No segregation (sedimentation of pure bitumen at the bottom of the jar) should occur.

Aggregate coating water resistance test: Samples of aggregate and emulsion are mixed and afterwards washed under specified test conditions. In this test the resistance to the effects of water on the coating of aggregate by cationic pre-mix grade emulsions is evaluated.

4.3.2 Specification for conventional emulsions

Applicable specifications for anionic and cationic emulsions are given in Tables 4.1 and 4.2.

NOTE: THE LATEST EDITION OF THE SABS SPECIFICATIONS SHOULD ALWAYS BE REFERRED TO.

Table 4.1: SABS specifications for anionic emulsions

Property	Test Method	Grade		
		Spray	Premix	Stable-mix
Viscosity @ 50°C, sec, Saybolt Furol	ASTM D244	20-50	20-50	-
Binder content, % (m/m)	ASTM D244	60-62	60-62	60-62
Residue on sieving, g/100 ml, max	SABS 309 (6.4)	0,25	0,25	0,25
Sedimentation, after 60 complete rotations	SABS 309 (6.5)	nil	nil	nil
Coagulation value, % (m/m):				
•Dolerite chippings, max	SABS 309 (6.2)	25	25	-
•Portland cement, max	SABS 309 (6.3)	-	-	2

Table 4.2: SABS specifications for cationic emulsions

Property	Test method	Grade					
		Spray 60%	Spray 65%**	Spray 70%*	Pre-mix 60%	Pre-mix 65%	Stable-mix 60%
Viscosity @ 50°C, sec Saybolt Furol	ASTM D244	20-50	51-200	80-200	20-50	51-200	50 (max)
Binder content, % (m/m)	ASTM D244	60-63	65-68	70-73	60-63	65-63	60-63
Fluxing agent content, % (m/m) of binder	ASTM D244	5 max	5 max	5 max	5-10	5-10	nil
Residue on sieving, g/100 ml, max.	SABS 548 (6.2)	0,25	0,25	0,25	0,25	0,25	0,25
Particle charge: - modified procedure - standard procedure	SABS 548 (6.3) ASTM D244	Pos -	Pos -	Pos -	Pos -	Pos -	Pos
Binder deposit on cathode after 30 min, g	SABS 548 6.3	1,0	1,0	1,0	-	-	-
Sedimentation after 60 complete rotations	SABS 548 (6.1)	nil	nil	nil	nil	nil	nil
Coagulation value, % (m/m): Silica flour, max	SABS 548 (6.5)	-	-	-	-	-	2,0

* Recommended specification.

** Large consumers of spray grade cationic (65%) emulsions specify a minimum viscosity requirement of 80 seconds Saybolt Furol at 50°C in order to reduce stone loss and run-off.

4.3.3 Recovery methods

The following two methods may be used to recover the base bitumen from an emulsion.

- *Rotary evaporator:* 300g $\pm$ 1g emulsion is placed in a 1 litre flask (or 500g $\pm$ 2g in a 2 litre flask) of the rotary evaporator (DIN 1996). The flask is then lowered into oil at 80°C $\pm$ 5°C. The flask is rotated at 50 rpm under a vacuum of 30 cm Hg $\pm$ 5 cm for 60 minutes $\pm$ 5 minutes. The temperature is raised to 150°C (the vacuum remaining unchanged) over a period of 15 minutes and then maintained at 150 °C $\pm$ 5°C for 60 minutes $\pm$ 5 minutes.

In case of a dispute, the rotary evaporator method is considered as the reference method.

- *Simple evaporation* (when the above method is not available). Approximately 160g of emulsion is added to the 1 litre container. This is then placed on a heating facility. The sample is then stirred with the thermometer at approximately 2 revolutions per second. Stirring is continued until the temperature of the residue is 150°C. The residue is then poured out for further testing. The heating rate should be such that the preparation is completed within 15 minutes.

4.3.4 Tests on recovered bitumen

The following tests are normally conducted on the recovered binder:

- Penetration - IP 49
- Viscosity - ASTM D4402
- Softening point (Ring and Ball) - ASTM D36
- Ductility at 10°C - DIN 52013.

Penetration test: The penetration of a bitumen is defined as the distance in tenths of a millimetre that a standard needle will penetrate into the bitumen under a load of 100 g applied for 5 seconds at 25°C. This test measures the relative hardness or consistency of penetration grade bitumens.

Softening point test: This test is also referred to as the Ring-and-Ball Softening point test. The temperature at which a disc of penetration grade bitumen softens sufficiently to allow a steel ball, initially placed on the surface, to sink through the disc and a further prescribed distance is determined. In this test the temperature at which bitumens have a particular consistency is measured.

Ductility test: The ductility of a bitumen is expressed as the distance in millimetres to which a standard briquette can be elongated under specified conditions before the thread so formed breaks. This test is a measure of the cohesiveness or adhesiveness and elasticity of the bitumen under a slowly applied load.

4.3.5 Specifications for recovered bitumen

The recovered bitumen should comply with the requirements of SABS 307⁽⁹⁾ (penetration grade bitumens).

4.4 TESTS AND SPECIFICATIONS FOR MODIFIED EMULSIONS

4.4.1 Tests on modified emulsions

The same as those described in section 4.3.1.

4.4.2 Specification for modified emulsions

The specifications given in Table 4.3 are based on guidelines provided by the Sub-committee on modified binders of the Bituminous Materials Liaison Committee (BMLC)⁽¹⁰⁾.

NOTE: THE LATEST AVAILABLE AND APPLICABLE SPECIFICATION SHOULD ALWAYS BE REFERRED TO.

Table 4.3: Interim specification for modified emulsion (homogenous binders)

Property	Test Method	SBR modified		SBS modified	
		65%	70%	65%	70%
Modified binder content, %, (min).	ASTM D244	65	70	65	70
Viscosity @ 50°C, seconds Saybolt Furol, (min).	ASTM D244	70	80	50	80
Residue on sieving, g/100 ml, (max).	SABS 548 (6.2)	0,25	0,25	0,25	0,25
Particle charge	SABS 548 (6.3)	Pos	Pos	Pos	Pos
Sedimentation after 60 complete rotations	SABS 548 (6.1)	nil	nil	nil	nil

4.4.3 Recovery methods

The same as those described in section 4.3.2.

4.4.4 Tests on recovered bitumen

The same as those described in section 4.3.3. In addition, the *elastic recovery* is measured by means of a ductilometer. The method is briefly described below.

With the same equipment (DIN 52013) and under the same conditions as those used for measuring the ductility at 10°C, the briquettes are stretched to 200 mm. They are held at this position for five minutes, after which the threads are cut approximately in half with scissors. The briquettes are then left undisturbed for one hour, after which the half specimens are retracted until the two cut ends touch. The elongation at this point (in mm) is noted and the percentage recovery is determined as follows:

$$\% \text{ recovery} = (200 - \text{"elongation (mm)"}) / (200) \times 100.$$

The modified Vialit test in conjunction with aggregate can also be used to evaluate the properties of the recovered modified bitumen (see Section 10.7).

4.4.5 Specifications for recovered modified binders

The specifications given in Table 4.4 are also based on guidelines provided by the Sub-committee on modified binders of the Bituminous Materials Liaison Committee (BMLC)⁽¹⁰⁾.

NOTE: THE LATEST AVAILABLE AND APPLICABLE SPECIFICATIONS SHOULD ALWAYS BE REFERRED TO.

Table 4.4: Interim specifications for recovered binder from modified emulsions (homogenous binder).

Property	Test Method	SBR modified		SBS modified	
		B8	B4	B8	B4
Softening point, °C, (min).	ASTM D36	55	45	60	47
Viscosity @ 135°C, dPa.s, (Brookfield), (min).	ASTM D 4402	1,3	1,0	1,3	1,0
Ductility @ 10°C, mm, (min).	DIN 52013	1 000	1 000	500	500
Elastic recovery @ 10°C, %, (min).	Section 4.4.4	52	55	55	60
Adhesion (Vialit) @ 5°C, (min).	Section 10.7.1	90	90	90	90
Adhesion (Vialit) @ 50°C, (min).		100	100	100	100

The bitumen source and presence of flux may have an effect on the change in properties after recovery. An indication of potential variations in the increases in the Ring and Ball softening points of polymer-modified base bitumens from various sources with and without flux is given in Table 4.5. It is, therefore, recommended that suppliers state the flux content of the delivered product.

Table 4.5: Variations in the increase in Ring and Ball softening points of modified B8 (80/100 Pen) base bitumens from various sources.

Source	With Flux (°C) (with SBR)	Without Flux (°C) (with SBR)
A	+ 8	+ 11
B	+ 10	+ 17
C	+ 13	+ 17

5. EMULSION-TREATED BASES

5.1 GENERAL

Emulsion-treated bases cover a wide range of granular materials, ranging from high-quality materials (e.g. G1) to sub-standard materials. These include emulsion modification or stabilization of the following granular materials:

- substandard materials;
- other granular materials of good quality (up to G1/G2 materials);
- recycled old granular bases (may include bituminous surfacing subject to oversized constraints)
- recycled cemented bases (in equivalent granular state); and
- combinations of any of the above.

When the emulsion-treated material satisfies the material and design criteria given in the Sabita manual⁽¹¹⁾, these mixes are then referred to as Granular Emulsion Mixes (GEMS).

GEMS may be used in a wide range of applications, from surface courses for light pavement structures to bases for high-volume roads. This is possible as the emulsion content can be varied and the appropriate aggregate selected to yield mixes with suitable engineering properties.

5.2 BEHAVIOUR OF GEMS

The behaviour of GEMS is more complex than that of asphalt. Asphalts are two-component systems comprising aggregate and bitumen, whereas GEMS are multi-component systems containing aggregate, bitumen, water and (where required) lime or cement.

In addition, asphalt is a visco-elastic material whose stiffness increases at lower temperatures and at higher rates of loading. GEMS have an additional feature which influences stiffness, namely the curing of the material. (The visco-elastic nature of GEMS is more significant at higher emulsion contents.)

On account of the significant influence of curing, its effects on the stiffness of GEMS should be considered in both the mix design and structural analysis of GEMS.

5.3 MODIFICATION OR STABILISATION

Many successful bases with low residual binder contents (as low as 0,7 per cent) have been constructed in South Africa. This approach produces bases that are less sensitive to water by facilitating compaction with resulting higher densities. During the curing process negative pore pressures are created which lead to improved shear resistance.

The general trend in Europe and the USA is to use large amounts of emulsion (from 3% to 8%) in combination with a wide range of materials. This general approach, from a design point of view, is to treat GEMS in a similar manner to asphalt.

In the case of GEMS the following two definitions should apply:

- *Modification:* This is the process in which GEMS are treated from a "gravel" approach, using test methods suited for that purpose, such as the CBR and UCS tests. In this approach residual binder contents generally lie between 0,6 and 1,5 per cent by mass of mix.
- *Stabilisation:* This is the process in which GEMS are treated from an "asphalt" approach, using test methods suited for that purpose, such as the Marshall and Indirect Tensile Tests. In this approach, residual binder contents generally range from 1,5 to 5 per cent by mass of mix.

The selection of the appropriate approach is based primarily on the following factors:

- design traffic class (material strength required) and
- material quality (material strength).

Some guidelines for the selection of the appropriate design approach are given in Table 5.1.

Table 5.1: Selection of the appropriate design approach (modification or stabilisation)

Material quality before treatment	Traffic class			
	E1/E0	E2	E3	E4
G1 to G3	not cost-effective	Modification	Modification	Stabilisation*/ Modification*
G4 to G6	Modification	Modification	Stabilisation*/ Modification*	Stabilisation*
Substandard (G7 and lower)	Modification	Stabilisation/ Modification	Stabilisation*	not suitable

* Care should be exercised when these design approaches are used.

5.4 MATERIALS

5.4.1 Emulsion

Stable grade anionic emulsions (60 per cent residual bitumen) are normally used for GEMS. There is currently a move towards using cationic stable grade emulsions due to the rising costs and short supply of certain agents.

5.4.2 Aggregate

When G1 to G5 materials are used, the aggregate in the base should comply with the recommendations contained in TRH4⁽¹²⁾ and TRH14⁽¹³⁾. In the case of sub-standard materials, the specifications given in the Sabita manual on GEMS⁽¹¹⁾ should be adhered to.

5.4.3 Lime and cement

If the PI of the aggregate exceeds the prescribed level (7 in the case of the Stabilisation approach and 6 in the case of the Modification approach) the material should be treated with lime or cement in order to reduce its PI to an acceptable level⁽¹¹⁾. Lime or cement should be added to the aggregate before any emulsion or mixing water is added. The use of cementitious binders, especially cement, has the added advantage of accelerating the curing process.

The benefits of using materials with low PIs or even non-plastic materials cannot be over-emphasized.

Further details of the suitability of various materials with lime and emulsion treatment are given in the Sabita manual on GEMS⁽¹¹⁾.

5.5 MIX AND STRUCTURAL DESIGN

These are described in detail in the Sabita manual on GEMS⁽¹¹⁾ and summarized in Appendix A. It is, however, important to bear in mind the two different design approaches.

5.5.1 Modification design approach

This approach uses the conventional design equipment as required for granular material. Aspects of importance include:

- laboratory compaction using the modified AASHTO method (150 mm diameter samples);
- only final curing (45 hours at 60°C);
- testing in terms of ITS, UCS (Unconfined Compressive Strength) and CBR (California Bearing Ratio); and
- design criteria in terms of CBR and UCS.

Analysis of the GEM layer is similar to that of a conventional granular base, using the safety factor concept. In the case of GEMS, however, the cohesion values may be doubled.

5.5.2 Stabilisation design approach

The mix design during the stabilisation approach makes use of a Modified Marshall approach. This approach uses concepts such as:

- laboratory compaction using the 75-blow Marshall method (100 mm diameter samples);
- both initial and final curing (20 hours at 60°C) in the laboratory;
- testing in terms of the Marshall parameters, Indirect Tensile Strength (ITS) and the Indirect Tensile Stiffness; and
- exposure to water using the capillary method as required.

In the structural design process, the mode of failure is considered to be fatigue. Some important aspects include the following:

- During the structural analysis, the curing period is divided into quarters using different stiffnesses which in turn are functions of the rate of curing.
- The life of the GEM layer is determined from fatigue curves and applicable conversion relationships.

5.6 CONSTRUCTION

Details of construction and quality control are given in the Sabita manual on GEMS⁽¹⁾. The relevant clauses of the CSRA specification⁽⁶⁾ also apply.

Three aspects are considered significant in the quality control of GEMS, namely:

- when the modification approach is used the PI should not exceed 6 and should preferably be lower (lower PIs will result in improved mixtures);
- under no circumstances should undiluted emulsion come into contact with dry aggregate; and
- proper compaction is extremely important.

5.7 CONSTRAINTS

The following are a number of factors that may influence the decision to use GEMS:

In case of stabilised GEMS, unrestricted traffic should not be allowed on the newly constructed base. Provision should be made for a period of curing (without any traffic). The length of this period may depend on the emulsion content, presence of cement, type of aggregate and environmental conditions and it could vary between a few days and two weeks. It is emphasized that, if it is practically possible to prevent traffic for longer periods, this should be considered.

The use of Dynamic Cone Penetration (DCP) measurements could characterise the strength increase of the GEM and could assist in judging the appropriate length of the controlled curing period.

Whenever good aggregate is available, the modification approach is generally more appropriate. If good quality material has to be imported, the use of locally available lower- or sub-standard materials in combination with greater amounts of emulsion (stabilisation approach) may be more economically attractive.

As various types of aggregates (of different geological origins) may react differently with emulsion, lime and cement, the compatibility of these materials with emulsions should be confirmed.

6. PRIME COATS

6.1 GENERAL

A prime coat is a bituminous binder applied to a granular or a GEM layer before the application of an asphalt base or bituminous surfacing. It promotes adhesion between the granular layer and the bituminous layers, helps to seal surface pores in the granular layer and binds the finer aggregate near the surface of the granular layer.

6.2 MATERIALS AND EMULSION SELECTION

Standard anionic and cationic emulsions should not be used as primes as these do not penetrate the granular layers.

An invert emulsion (SABS 1260⁽¹⁴⁾), in which the continuous phase is a low viscosity bitumen and the dispersed phase is water, can be used as a prime coat. This type of emulsion has been used effectively where the possibility of salt damage may arise.

Non-ionic emulsions may also be used as primes.

6.3 CONSTRUCTION

The surface of the base should be well broomed with a mechanical broom until all loose (natural and foreign) material has been removed. Moistening the surface with a light sprinkling of water immediately before priming, particularly in the case of gravel bases, reduces the surface tension and helps the prime to cover the surface uniformly and to adhere to the base.

The prime should be sprayed with a binder distributor calibrated to give an accurate rate of application and tested for satisfactory transverse distribution according to TMH2⁽⁷⁾.

More guidelines on construction are given in TRH1⁽¹⁵⁾.

6.4 CONSTRAINTS

The main factors governing the selection of the type and grade of prime and its rate of application are the type of granular layer, its absorptive characteristics and the moisture content of the base.

Priming should not be carried out when the road surface temperature is below 10°C, or when the spraying performance of the distributor might be affected by wind or when rain is threatening.

7. CURING MEMBRANES

7.1 GENERAL

If it is not possible to cover the cemented layer with either a subsequent layer or surfacing within 24 hours, a curing membrane may be constructed. The purpose of this curing membrane is to prevent moisture loss and thus promote the hydration process (by allowing for the necessary period of slow curing) to prevent any detrimental carbonation or salt migration and to provide a waterproof membrane to protect the stabilised layer against surface water.

7.2 MATERIALS AND EMULSION SELECTION

The most effective binders for curing membranes are anionic and cationic spray grade emulsions (see section 2.1.4).

7.3 CONSTRUCTION

The curing membrane should be applied within an hour of placement of the cemented layer. Suitable spray rates vary between 0,65 and 1,00 litre/m². Recommended spraying temperatures are given in Table 3.3.

Care should be taken (such as by proper brooming) to ensure that a good bond between the curing membrane and a cemented base is obtained so as to prevent any subsequent slippage causing failure of bituminous surfacing.

Details of the construction of curing membranes are given in TRH1⁽¹⁵⁾.

7.4 CONSTRAINTS

Traffic should not be allowed on curing membranes, as vehicle tyres will pick up the membrane. However, if trafficking is unavoidable, a blinding layer of natural sand or of crusher sand should be applied. The placing of this blinding layer should be postponed as long as possible. If this pavement layer is to be used as a final layer and if the application of this type of blinding layer may lead to punching of the final seal, then a 6,7 mm blinding material using an inverted double seal approach is recommended.

8. TACK COATS (ASPHALT)

8.1 GENERAL

A tack coat provides improved adhesion between an existing surface and a new asphalt overlay or surfacing. A bitumen emulsion tack coat may also be used as a curing membrane for cement-treated bases.

Tack coats are normally required to ensure adequate adhesion between a newly applied asphalt and the existing surface. They are usually applied in the following cases:

- when an asphalt layer is applied on a concrete road or bridge deck;
- when an asphalt layer is applied over a previously primed surface which has become excessively dusty or which has dried out excessively;
- when an asphalt overlay is applied to an existing bituminous surfacing;
- when an asphalt layer of 40 mm or less is laid;
- in areas where exceptionally high shearing stresses are induced e.g. at steep gradients or sharp bends; or
- during periods of cool or moist weather or when the site is in a shaded area.

8.2 SELECTION OF MATERIALS AND EMULSION

The use of an anionic stable grade (60 %) emulsion is suggested. This should be diluted with water in the ratio 1:1 and applied according to the spray rates given in Table 8.1.

Cationic spray grade emulsions may also be used and can be diluted in a 1:1 ratio with compatible water, after consultation with the supplier (refer para 2.2.2), should anionic stable grade emulsion not be available.

Table 8.1: Recommended spray rates for tack coats (for asphalt)

Surface condition	Spray rate (cold net) litre/m ²
Very smooth asphalt surface or concrete	0,27
Smooth asphalt surface	0,41
Dry ("hungry"), rough or badly cracked bituminous surfacing	0,54
Very open bituminous surfacing	0,68

8.3 CONSTRUCTION

Before the asphalt is laid, the emulsion should be allowed to break completely. Localized depressions into which emulsion may have drained should be cleared of any unbroken emulsion before the asphalt is laid.

8.4 CONSTRAINTS

Tack coats should not be applied during periods of cold or wet weather. The best conditions are when the surface is dry, the air temperature is above 10°C and rising and when there is no threat of rain.

Traffic should be kept off the tack coat prior to placement of the asphalt. If this is not possible, the speed limit should be kept below 30 km/h mainly for safety reasons.

9. PRE-COATING OF AGGREGATE

9.1 GENERAL

Diluted or purpose-made emulsion may be used as a pre-coating fluid during the construction of surface treatments to improve the wetting and adhesion of surface seal aggregate to cutback, road (penetration) grade, homogeneous modified road grades (polymer) or non-homogeneous modified binders (bitumen-rubber).

9.2 MATERIAL AND DESIGN

Anionic or cationic emulsions with low viscosities and bitumen contents of 20% to 30% are generally suited for this type of application.

The quantity of pre-coating fluid necessary to coat the stone properly may vary considerably depending on the absorptive properties of the stone, the size of the stone, the amount of moisture and dust present and the type of pre-coating material. Care should be taken not to overcoat the stone.

The emulsion manufacturer should be consulted on the particular grade of emulsion to be used.

9.3 CONSTRUCTION

Pre-coating of the stones can be carried out on site using a mobile pre-coating machine or other suitable equipment.

9.4 CONSTRAINTS

The use of pre-coated stone is not recommended where emulsion is used as the binder in a surface treatment.

10. EMULSION SURFACE TREATMENTS

10.1 GENERAL

10.1.1 Surface treatments

In this section the use of emulsions in surface treatments is discussed. The following types of surface treatments are discussed:

- single seals;
- double seals;
- Cape seal;
- conventional slurries; and
- microsurfacing (e.g. rapid-setting polymer-modified slurries).

10.1.2 Purposes of surface treatments

The main purposes of surface treatments are:

- to protect the pavement layers against the ingress of surface water and effects of traffic;
- to provide a sound surface and ensure good ridability (including reduction of dust pollution), and
- to provide a safe road surface in terms of skid-resistance.

10.1.3 Safeguards

Care should be taken to ensure the correct selection and use of materials in order to prevent aggregate loss or bleeding during trafficking.

10.1.4 General constraints

Gradient constraints are important in order to limit damage caused by water run-off and by shoving. The same constraints may be equally applicable to sharp bends. The gradient limits for surface treatments are given in Table 10.1. The lower end of the ranges would be more appropriate for seals using emulsion binder because of potential run-off problems.

Table 10.1: Gradient limits for surface treatments⁽¹⁰⁾

Type of surface treatment	Gradient (%)
Coarse slurry	6 - 8%
Single seal	8 - 12%
Cape seal, double seal	12 - 16%

Highly absorptive aggregates require special consideration. The use of modified emulsions, such as SBR-modified emulsion, is one method of reducing the risk of absorption.

When the emulsion is to be *diluted*, the compatibility of the water to be mixed with the emulsion should be verified (see section 2.2.2). Water which is fit for human consumption is usually suitable for cationic emulsions (both spray and stable grades) and for anionic-stable grade emulsions. Anionic emulsions (both spray and pre-mix grades) should not be diluted.

The *weather conditions* when emulsions are used should be taken into consideration. Emulsions should not be applied:

- during damp or rainy weather;
- when the wind speed is such that it may adversely affect the spraying operation;
- when there is free water on the road, or
- when the temperature of the road immediately prior to the application of the emulsion is below 10°C.

Reduced working hours should apply where weather conditions mitigate against adequate breaking of emulsions, e.g. during winter in the Western Cape.

The condition of the *base* should be considered. Surface treatments (or primes) should not be applied unless the moisture content of the underlying granular base course is less than 50 per cent of optimum moisture content (OMC).

10.2 SINGLE SEALS

The following types of single seals with emulsions are commonly used:

- single seal of 4,75 mm chips;
- single seal of 6,7 mm chips;
- single seal of 9,5 mm chips plus a blinding layer of sand;
- single seal of 13,2 mm chips plus sand; and
- single seal of 13,2 mm chips plus grit.

9,5 mm and 13,2 mm single seals without grit or sand may be used where it is possible to prevent trafficking for a few days.

The selection and application of the appropriate type of single seal is discussed in TRH3⁽⁵⁾. 4,75 mm chips are also used for the texturing of existing surfacings or in reseals on low-volume roads.

10.2.1 Selection of materials and emulsion

Aggregates should conform to the latest specification issued by the SABS. There are three grades. The differences in the fines content ($< 0,425$ mm) and dust content ($< 0,075$ mm) are the main difference between grades 1 and 2. There is a relaxation in fines and dust contents and in the gradation of grade 3 aggregates. The material properties of grades 1 and 2 are given in Table B1 and those of grade 3 are given in Table B2 of Appendix B. Grade 1 and grade 2 aggregates are generally used with modified emulsions and grade 2 and grade 3 with conventional emulsions.

The aggregates used in seal work should not be precoated if emulsions are used for spraying. The absorption characteristics of the uncoated aggregate facilitates the breaking process of the emulsion.

Cationic spray grade (65 or 70%) emulsions or SBR-modified emulsions are recommended for use in single seals.

SBR-modified emulsions perform well with absorptive aggregates, where heavy traffic conditions prevail, and/or where deflection bowl or crack activity characteristics (with certain limitations) require higher performance binders.

Cationic (70%) spray grade emulsions are mainly used in areas with steep super-elevations, steep gradients and in shady areas. They can also be used in cases where they are more economical (such as where haul distances are long,) or where it is necessary to limit the maximum spray application.

The type of base bitumen in an emulsion is important in terms of its relationship to temperature. It is suggested that a B8 (80/100 Pen) bitumen be used during the warmer months (e.g. October to April) and a B4 (150/200 Pen) bitumen be used during the cold months (e.g. May to September). Emulsion made with B4 (150/200 Pen) bitumen may be used during the summer months in areas with low traffic volume s.

10.2.2 Design procedures

Details of the design of single seals are given in TRH3⁽⁵⁾.

In the case of single seals plus grit, split applications are normally used. The calculated penetration layer application rate for 13,2 mm aggregate is normally increased by 0,2 litre/m² emulsion, to allow the grit to be put in place prior to the breaking of the emulsion.

10.2.3 Guidelines for construction

Guidelines for the construction of seals are given in TRH3⁽⁵⁾. The following aspects are considered to be important.

Aggregate should be spread on the layer of emulsion as soon as possible after application. After the aggregate has been spread, the aggregate chippings should not be disturbed by brooming unless they have been spread by means other than by a mechanical spreader. The aggregate should be given an initial rolling with a light (4 to 6 ton) steel-wheeled roller, which will bed the chippings and aid in the breaking process of the emulsion. Pneumatic-tyred rollers should not be used for this initial rolling as they cause the chippings to turn slightly, exposing the binder, which then adheres to the tyres of the roller.

After the emulsion has broken and before the road is opened to traffic, the seal should be back-rolled during the warm period of the day with either a steel-wheeled or pneumatic-tyred roller. Under favourable conditions this process can be completed during the same day.

In cases where seals are laid on cemented bases, care should be exercised during the rolling process, as heavy steel rollers may crush the aggregate.

If the temperature of the existing road surface exceeds 60°C, light watering of the surface is suggested before the emulsion is applied.

10.2.4 Constraints

See section 10.6.4.

10.3 DOUBLE SEALS

A double seal (with emulsion) generally consists of a spray of emulsion, 13,2 mm (or 19 mm) aggregate chips in a single layer (shoulder to shoulder contact in the binder), a second spray of emulsion, and a second layer of 6,7 mm (or 9,5 mm) aggregate chips, which is then followed by a fogspray. Other aggregate sizes may also be used for specific applications.

An inverted double seal consists of a first layer of 6,7 mm aggregate chips and a second layer of 13,2 mm aggregate chips. This type of seal is generally used in rehabilitation projects when a light seal is required for early trafficking. The inverted double seal is generally designed as two separate single seals.

10.3.1 Selection of materials and emulsion

Cationic (65% or 70%) spray grade or SBR-modified cationic emulsions are normally used for both applications of the binder. Where high temperature conditions prevail the use of anionic spray grade emulsion is favoured on account of its slower breaking characteristics.

A fog spray consists of either stable grade anionic or cationic emulsions which may have been diluted in water. Cationic spray grade emulsion may also be used, which has been diluted in water (refer para 2.2.2).

See section 10.2.1 for details of aggregates and of the use of SBR-modified emulsions.

10.3.2 Design procedures

Details of the design of double seals are given in TRH3⁽⁵⁾.

10.3.3 Guidelines for construction

The guidelines given in section 10.2.3 should be followed.

10.3.4 Constraints

Sufficient time should elapse prior to the application of the second spray to ensure that all the volatiles or water in the first spray have evaporated. If any volatiles are trapped by the second spray, bleeding or richness of the surfacing could result.

See also section 10.6.4.

10.4 CAPE SEAL

Cape seal generally consists of the application of a binder and 19,0 mm aggregate chips followed by two applications of slurry. In the case of roads with low traffic volumes, 13,2 mm aggregate chips and a single application of slurry may be used.

10.4.1 Selection of materials and emulsion

The 19,0 mm or 13,2 mm aggregate chippings (Grade 1 and Grade 2) and the aggregate for the slurry should conform to the guidelines given in TRH14⁽¹³⁾ and the CSRA Standard Specifications⁽⁶⁾.

The slurry should contain a Portland cement active filler which complies with SABS 471⁽¹⁶⁾ or an approved alternative.

For the first spray, the use of cationic 65% or 70% spray grade or SBR-modified emulsions is suggested. Diluted anionic spray grade or cationic (30%) emulsions are normally used in the second spray (refer para 2.2.2). Stable grade emulsion used in slurries may also be used in a diluted form for the second spray.

A fine-graded slurry is preferred in a Cape seal. The grading requirements for this type of slurry are given in Table B3 of Appendix B. Stable grade 60% anionic emulsion is generally used for the slurry. Cationic stable grade emulsions have been used successfully when early breaking is required. However, a high dust content in the slurry aggregate and long hauls may result in early breaking.

10.4.2 Design procedures

The design procedure for Cape seals is given in TRH3⁽⁵⁾ and the CSRA Standard Specifications⁽⁶⁾

10.4.3 Guidelines for construction

Construction of Cape seals is discussed in TRH3⁽⁵⁾.

The aspects below need special consideration.

The consistency of the slurry, measured in accordance with ASTM D3910⁽⁸⁾ should normally be between 30 mm and 40 mm in order to achieve the required workability (see para 10.7.2).

The use of hand-held squeegees is preferred on the first layer. They should be used in a multi-directional fashion in order to fill the voids adequately. Mechanical application processes have also been used with success.

There are different approaches with regard to the timing of the application of the second layer. The advantages of a period of trafficking (e.g. one month) are:

- additional traffic compaction with a deeper penetrating effect of the tyre treads, and
- earlier accommodation of traffic.

Another approach is to apply the second layer within two weeks to overcome the following disadvantages of the first method:

- contamination and difficulties of the removal of contamination, with resulting loss of adhesion between the first and second layers; and
- if the first layer is not completely impermeable, water may penetrate the existing pavement structure.

The top layer of the last application of slurry should be brushed so as to leave the tops of the aggregate slightly exposed, yielding a macro texture to promote skid resistance.

Rolling of each layer of slurry should commence after the slurry has dried sufficiently. Each layer of slurry should be roller compacted with a 27 ton pneumatic-tyred roller. The gradation of the slurry together with adherence to the stated procedures should yield Marvil permeabilities of less than 1 litre/hour.

10.4.4 Constraints

During hot weather it is frequently observed that, as the day advances, the underlying stone layer of the Cape seal is increasingly disturbed by the slurry operations. When this occurs, it is recommended that operations be suspended during the heat of the day and that the work be done during early morning and late afternoon.

10.5 CONVENTIONAL SLURRY

Conventional slow-setting anionic coarse slurries are used for treatment of existing road surfaces which are subjected to low traffic volumes and which may exhibit any of the following defects:

- uneven surfaces because of bumps and rutting;
- smooth surfaces resulting in low wet-weather skid resistance, or
- when low-activity surface cracking is present.

Medium and fine slurries are normally applied as surface-texture treatments. In the case of active cracks, the use of these slurries can be reasonably effective in the short-to-medium term.

10.5.1 Selection of materials and emulsion

The aggregate grading of a slurry should be considered in conjunction with the surface texture of the existing surfacing. In the case of coarse open-textured surfaces, where skid resistance properties are satisfactory and where the prevention of the ingress of water to the base is important, a fine grading is desirable. However, fine-graded slurries can become slippery under high traffic volumes; coarse-graded slurries are more suitable under high traffic volume conditions. Therefore the choice of the grading is related to the dual requirements of sealing and skid resistance. The CSRA specifications⁽⁶⁾ refer to fine, medium and coarse gradings to be used for slurries.

Further details of aggregate requirements are given in TRH14⁽¹³⁾.

The addition of Portland cement active filler or of any other approved alternative (normally 1%) improves the dispersion of the aggregate particles and improves the workability of the slurry.

The emulsion should preferably be a stable grade anionic (60%) emulsion with B8 (80/100 Pen) base binder. However, in cold regions during the winter months emulsions with B4 (150/200 Pen) base bitumen may be used.

10.5.2 Design procedures

The design of slurries is discussed in TRH3⁽⁵⁾.

10.5.3 Guidelines for construction

A purpose-designed machine should be used for the mixing and application of the slurry. This machine should be capable of continuous mixing and application and should be equipped with accurate metering systems to enable the various constituents to be combined. A central mix plant should not be used.

Prior to placement of the slurry, the road surface should be moistened. The spreader box should be of a proven and approved type. It should be so constructed as to distribute the weight of the box onto metal skids in such a way that no damage occurs to the existing surfacing. The spreader box should be capable of spreading the slurry uniformly in adjustable widths. The final surface texture can be improved by means of a burlap drag or by hand brooming.

Sufficient rollers of the correct type should be available. A pneumatic-tyred roller with a mass of not less than 10 ton should be used. The wheels should be so spaced that one pass of the roller will provide one complete coverage equal to the rolling width of the machine. Rubber-soled steel-wheeled rollers with a mass of between 6 and 8 tons should also be used. All rollers should be self-propelled.

The construction of slurries should be included in the appropriate project specifications, with special reference to joints and compaction to ensure impermeability and stability.

10.5.4 Constraints

After application of the slurry, the road should be kept closed to traffic until the slurry is completely set. This may vary from 1 hour on warm days to 4 hours or more on cold days.

Slurry should not be applied at ambient air temperatures of less than 7°C and rising or less than 13°C and falling. Special precautions are required to reduce the road surface temperature during hot weather, such as a light spray of water or postponement of work until the cooler part of the day. Slurry operations should be suspended when rain is imminent. When strong wind conditions exist which are likely to interfere with the proper execution of the work, no slurry work should be conducted.

As slurries become unstable under traffic during hot weather they should not be applied in layers thicker than those indicated in Table 10.2

Table 10.2: Suggested layer thickness for fine, medium or coarse slurries

Aggregate grading of slurry	Recommended range of layer thickness
Fine-graded	2 to 3 mm
Medium-graded	3 to 6 mm
Coarse-graded	6 to 10 mm

10.6 RAPID-SETTING COARSE SLURRY (MICROSURFACING)

Under conditions of high traffic volumes and (extreme) low temperatures a rapid-setting polymer-modified slurry (microsurfacing) is preferable to conventional slurries (section 10.5). Rapid-setting slurries may be used under the following conditions:

- where the surface is uneven because of bumps and rutting;
- where the edges of the surfacing require reinstatement;
- where the surface texture needs improvement or resealing for high volume, low axle load applications ($\leq$ E1 traffic);
- where the areas to be treated are in shade;
- where rainy conditions limit construction operations; or
- where dictated by traffic accommodation.

Rapid-setting slurries can tolerate more adverse weather conditions than normal slurries and can be laid at ambient air temperatures of between 4 and 40 °C and also under damp road conditions.

Rapid-setting slurries can be used for filling ruts deeper than 10 mm. These slurries can be placed on the existing road surface without tack coat. Each layer is normally capable of carrying traffic within 30 to 40 minutes of laying.

10.6.1 Selection of materials and emulsion

The type of grading is dictated by the specific project needs. Type 1 gradings (maximum stone size of 9,5 mm) are used for levelling and filling ruts with depths up to 20 mm. Type 2 gradings (maximum stone size of 13,2 mm) are used for wearing courses, edge breaks and for filling ruts greater than 20 mm in depth.

The presence of deleterious clay minerals could render certain aggregates unsuitable. The methylene blue adsorption test is a rapid means of determining whether the clay in the fines of an aggregate contains deleterious swelling clay minerals, such as smectites, caused by the weathering of rock. The method also indicates the extent to which an aggregate should be further investigated in order to determine its suitability for specific applications.

The active filler should be Portland cement conforming to SABS 471⁽¹⁶⁾ or an approved alternative.

The recommended emulsion should be a polymer-modified cationic stable grade emulsion blend with a solids content (bitumen, emulsifiers and rubber modifier) of 65 ± 2 per cent. The base bitumen would be B8 (80/100 Pen) grade bitumen. (B12 (60/70 Pen) has also been used in certain warm regions, but should only be specified where appropriate in consultation with the supplier.)

After the slurry has been laid, the residual binder should have the properties given in Table 10.3.

Table 10.3: Residual binder properties of rapid-setting polymer rubber- modified coarse slurry.

Property	Limit	Test method
Softening point (Ring and Ball) (°C)	58 - 64	ASTM D36
Penetration at 25°C (mm x 10 ⁻¹)	50 - 65	IP 49
Fraass brittle point (°C)	-17	DIN 52012

10.6.2 Design procedures

Proven designs are normally supplied by the emulsion manufacturer.

10.6.3 Guidelines for construction

The production of rapid-setting slurries should be similar to that of conventional slurries (see section 10.5.3). In addition, the purpose-designed machine for mixing and application should be capable of providing a rapid mixing time and

sufficient agitation within the spreading systems to prevent segregation or premature setting.

Rolling of the slurry commencing at the appropriate stage after laying as established in a trial section, using a pneumatic-tyred roller will significantly increase its stability and impermeability. Premature rolling may result in flushing up of the fines and binder. The construction of a trial section is therefore recommended to assess the correct stage for rolling. The Marvil permeability test and visual assessments will assist in judging the time delay prior to commencing with roller compaction as well as the required number of passes. (Typically such trial sections in the Western Cape yielded 30 to 40 minutes delay before commencing such rolling operations.)

10.6.4 Constraints

Road temperatures at the time of placing should not exceed 60°C.

10.7 EVALUATION AND TESTING OF SURFACE TREATMENTS

10.7.1 Adhesion

The Vialit adhesion test may be used to assess the adhesion properties of seals constructed with emulsions. Typical criteria for SBR- and SBS-modified emulsions are given Table 4.4. A brief summary of the method is given below.

The emulsion is coated onto 200 x 200 mm steel plates. Within 8 minutes of the plates being coated, 100 standard 9,5 mm chips of the aggregate used in the project are placed (evenly spaced) on each plate. The plates are conditioned in an oven at 50°C for 24 hours. After conditioning, half the plates are placed in a cooling cabinet at 5°C and the remainder in an oven at 50°C.

After 45 minutes (minimum) conditioning at the desired temperature each plate is turned upside down in the Vialit apparatus and a 500 g steel ball is dropped from a height of 500 mm within 15 seconds. The test is run in duplicate at each temperature. The numbers of chips dislodged for each temperature are counted and the percentage chips adhering to the plate is calculated and recorded.

10.7.2 Consistency (slurries)

The consistency of slurries can be determined with the Kansas Cone Consistency Test, or simply called the Cone test. This test gives a numerical value to consistency.

This test uses the sand absorption cone (ASTM C-128) and a base flow scale. The cone is a hollow 0,8 mm frustum, 75 mm high with 40 mm top and 90 mm bottom diameters. The flow scale has 7 concentric circles inscribed on an industrial tile, metal sheet or paper, whose radii progressively increase by 1cm

from that of the circle formed by the large end of the cone.

Optimum values are considered as 2,5 cm radial flow with limits of 2,9 cm to 3,0 cm and a reproducibility of $\pm 0,25$ cm.

10.7.3 Permeabilities

It is recommended that the permeabilities of slurries and seals be measured by the Marvil permeability meter. Criteria for slurries and Cape seals are given in Table 10.4.

The Marvil permeameter consists of a cone manufactured from 3 mm steel (a height of 114 mm, bottom opening 175 mm in diameter and a top opening of 60 mm in diameter). Attached to the top of the steel cone is an acrylic tube 60 mm in diameter and 316 mm in height.

The cone-shaped steel plate is placed on the road surface and sealed using "Prestik" and an appropriate type of grease. The acrylic tube is then attached to the steel cone and quickly filled with water to just above the zero mark. The time that the water level takes to fall from zero until it reaches 300 ml maximum (or any other level, up to 300 ml depending on the permeability of the surface) is then recorded. The permeability of the surface material is then expressed in litres/hour.

Table 10.4: Criteria for the Marvil permeability of various surface treatments

Type of surface treatment	Permeability (litre/hour)
Slurries	< 0,5
Cape Seals	< 1,0

11. COLD-MIXED ASPHALT

Cold-mixed asphalt is produced when relatively large amounts of emulsion are mixed with high-quality aggregates blended to specific gradings (e.g. open- or continuously-graded). Experience has shown that cold-mix asphalt does not perform as well as hot-mix asphalt. This, however, may be attributed to the manufacturing and control processes. Although the final behaviour of cold asphalt is similar to that of conventional asphalt, the former needs to cure in order to achieve its full strength. Difficulties may be experienced with the curing of continuously-graded and gap-graded cold-mixed asphalt on account of the low void contents of these gradings. Application of continuously- and gap-graded cold-mixed asphalt is therefore generally limited to surfacings not normally used in South Africa.

Open-graded cold-mixed asphalt cures relatively quickly and has been used effectively by road authorities. It is normally used for bridge decks when the use of conventional asphalt is uneconomical on account of the distance of the site from the asphalt plant. Open-graded cold-mixed asphalt is also used for sidewalks and for patching.

Cationic pre-mix grade emulsions with a B8 (80/100 Pen) base bitumen are normally used for open-graded cold-mixed asphalt.

Anionic as well as cationic stable grade emulsion can be used to provide cold mixes containing a large proportion of fine material. It will, however, cure slower than the mixes prepared with cationic pre-mix grade emulsion.

Open-graded cold-mixed asphalt is normally sealed with a fine slurry seal. This results in a relatively impermeable surfacing which can be assessed by means of the Marvil test.

12. EMULSIONS IN MAINTENANCE OPERATIONS

12.1 BACKGROUND

Regular maintenance operations can increase both the functional and structural life of pavements. In this section the use of emulsion in maintenance operations, such as patch repair, pothole repair, crack filling and general seal work, is described.

12.2 PATCH REPAIR

Patching may be defined as any rehabilitation work to pavement layers to repair local failures over an area of typically less than 50 m² and/or having a length of less than 25 m.

It is not unusual to see maintenance teams repeatedly patching certain localized areas. The primary causes for the poor performances of these patched areas could be related to the quality of the backfill material used, the low level of compaction, the effectiveness of the treatment methods (if any) and the presence of trapped subsurface water.

The approach set out below was devised using sound techniques together with consistently high-quality material and can be widely used with limited supervision. The method has been successfully implemented in contract work for various road authorities.

The top 150 mm of the layerworks, excluding bituminous surfacing, should be constructed with imported crushed stone materials (minimum G3 quality), treated with 3% emulsion and 1% cement (mass/mass). For the emulsion, an anionic stable-mix grade is preferred but cationic stable-mix grade may also be used. Depending on prevailing conditions such as traffic volumes, other combinations of emulsion content, lime or cement content, and material types compatible with the in-situ structure are also used by various road authorities. The flexibility of the patch work needs to be adaptable to the existing pavement structure (e.g. avoid a stiff patch material on a very flexible pavement).

The total fluid content (water and emulsion) should be adjusted to achieve optimum moisture content as determined in the modified AASHTO compaction test. The total fluid content should not exceed the optimum or the material will tend to "sponge" during compaction and remain wet for a long period.

Prior to backfilling the excavation should be moistened (if necessary) and compacted. The crushed stone material should be thoroughly mixed with the cement and emulsion using a small concrete mixer. Then the backfill material should be placed and spread in thin layers; no more than 75 mm for hand-propelled vibratory drum rollers or no more than 60 mm for plate compactors

and hand tampers. The top layers should be compacted to 100% of modified AASHTO maximum dry density.

Several tests have been used to control the quality of the backfilling process. Firstly, the moisture content of each layer should be such that when squeezed in the hand the material should not crumble (too dry) or leave free water on the hand (too wet). Furthermore, the material should be well compacted until a ringing sound is obtained from a hand tamper and no indentation can be observed. Care should be taken to compact the edges of the patch with hand tampers.

It is essential for the final depth (e.g. 30 mm) of the patch work to be properly surfaced with preferably hot-mix asphalt in order to prevent any build up or ingress of subsurface water. If hot mixed asphalt is not available or not practical to use, then cold asphalt should be used. Care should be exercised to ensure an impermeable seal as well as a good bonding of the new surfacing to the patch work and especially to the existing surfacing.

12.3 POTHOLE REPAIR

Emulsion-based mixes used for maintenance purposes have some advantages over conventional asphalts in that hot-mix plants are not required for their production. These mixes may be stored for up to six months. Emulsion mixes for pothole repairs can be divided into two types:

- mixes for immediate use, and
- mixes for long-term storage.

12.3.1 Immediate use

These mixes consist of about 5 to 10 per cent, anionic or cationic, pre-mix grade emulsion (by mass of total mix) with one of the aggregate gradings given in Table 12.1.

Central mix plants, small truck mixers or hand mixing may be used to manufacture these mixes.

Emulsion-based maintenance mixes which contain small amounts of solvent generally produce the best cold mixes. However, these mixes will not gain their full strength until the solvent has evaporated. Maintenance mixes for potholes should not be placed if there is excess mixing water present as this will extend the period of curing and delay the opening of the road. An active filler, such as cement, can be used to facilitate the breaking process which would also promote early strength development.

Table 12.1: Aggregate gradings for emulsion-based maintenance mixes

Sieve size (mm)	Cumulative percentage material passing		
	9,5 mm nominal	13,2 mm nominal	19,0 mm nominal
26,5			100
19,0		100	90 - 100
13,2	100	90 - 100	
9,5	90 - 100		56 - 80
4,75	55 - 85	44 - 74	35 - 65
2,36	32 - 67	28 - 58	23 - 49
0,300	7 - 23	5 - 21	5 - 19
0,075	2 - 10	2 - 10	2 - 8

12.3.3 Long-term storage

The aggregate gradings given in Table 12.1 and the quantities of emulsions mentioned in par 12.2.1 may be used for these mixes. Pre-mix grade cationic emulsions are normally preferred, as the specifications permit the presence of a certain amount of solvent.

Central mixing plants are generally used for the production of these maintenance mixes. These are stored in stockpiles. The stockpile life and workability of maintenance mixes are in direct proportion to the amount of solvent present.

These maintenance mixes are generally produced in summer for use during the winter months. Normally a thin crust which can be broken by a shovel forms over the surface of the stockpile. The material beneath this crust possesses the characteristics of freshly-made emulsion-based mixes.

12.4 CRACK FILLER

It is sound practice to seal cracks as soon as possible. Details of various types of cracks are given in TRH6⁽¹⁷⁾. Failure to seal cracks will result in accelerated pavement failure which is generally caused by the ingress of water.

Prior to filling the cracks, the area and the cracks should be cleaned by compressed air, steel wire brushes and brooming.

Stable grade anionic and cationic emulsions can be used for crack sealing. Mineral filled emulsion types including polymer-modified types are available in the market place. These types may be diluted and application is generally by brooming.

Small cracks (less than 3 mm in width) are difficult to seal effectively. In the case of larger cracks, slurry or emulsion mixed with sand should be forced into the crack until it is about 6 to 3 mm below the surface. After this has cured, the remainder of the crack should be filled with emulsion. The surface should then be blinded with crusher dust or sand in order to prevent pickup by the traffic.

Purpose-made mineral-filled emulsions with and without modifiers are available. These products are applied in diluted form by means of soft brooms. They have been used to treat freshly placed asphalt which had been rejected on account of non-attainment of specified densities with consequent high permeabilities. These products are also used to ensure impermeable joints for patch repairs.

12.5 FOG SPRAY

Fog sprays are light applications of diluted (modified or conventional) anionic or cationic stable grade emulsions or cationic spray grade emulsions to existing dry surfaces as surface enrichment measures. They can also be applied to newly constructed single seal surface treatments to counteract unexpected chip loss. The purpose of fog seals is to improve the retention of stone under traffic.

Normally the surface is dampened prior to application of a fog spray in order to enable the emulsion to flow around the aggregate. The emulsion should be allowed to break and set before traffic is allowed on the road. A breaking period of 1 to 4 hours (depending on environmental conditions) is suggested. If diluted emulsions are used, pre-wetting of the road surface is not generally necessary. Fog sprays should not be applied at road surface temperatures of 50°C and higher.

12.6 FINE-GRADED SLURRY

Fine slurry is mainly used for surface-texture treatments, specifically to provide a uniform texture and to prepare the surface for re-sealing. It is typically used on existing surfaces (seals and asphalt) where the texture in the wheelpaths is smooth (due to an absence of voids) as well as where the texture outside the wheelpaths is coarse due to excess voids.

12.6.1 Selection of material and emulsion

The aggregate used for fine slurries should conform to the grading requirements provided in Table 12.2. Goldmine sand, which has a rough surface texture, can be used effectively in the manufacture of these slurries.

The emulsion content for fine slurries is generally in the region of 160 to 180 litre/m³ when preparing the surface for re-sealing. An emulsion content in the region of 200 to 240 litre/m³ is suggested if the surface is not sealed shortly after the application of the slurry.

Table 12.2: Grading requirements for fine slurries

Sieve size (mm)	Cumulative percentage material passing
1,18	100
0,60	89 - 100
0,30	50 - 70
0,15	25 - 35
0,075	7 - 15

12.6.2 Design procedures

The design process is similar to that of conventional slurries. As this fine slurry is generally intended for texture treatments, a lower binder content is used in many cases, especially where the existing surface is "rich" in binder.

12.6.3 Construction procedures

Fine slurries are normally mixed in concrete mixers and are applied to the surface by means of brooms and squeegees. Where large areas need to be slurried, mechanical spreaders may be used.

It should be noted that slurry should only be applied to fill the interstices between the aggregate and that the slurry should not form a layer on the existing seal. The thickness of application is generally between 1 and 2 mm.

Compaction is not normally required for this type of texture treatment. However, traffic should be allowed on the slurry for at least two weeks in order to remove excess slurry and to provide additional compaction.

12.6.4 Constraints

Fine slurries should not be exposed to traffic for more than 3 months. After this period resealing is generally required.

12.7 SURFACE TREATMENT

The guidelines given in section 10 apply.

In addition, the following constraints are considered important:

The condition of the *existing base* should be considered. If a surface treatment is likely to trap moisture below the cracked surface, postponement of the resealing process for at least 48 hours after prolonged rainfall or for 12 hours after light showers is recommended.

The use of surface treatments is also limited by the extent of the *crack activity*. The use of surface treatments is subject to the conditions indicated in Table 12.3.

Table 12.3: Recommended types of emulsion-based surface treatments for various degrees of crack movement

Type of surface treatment	Crack movement (μm)	Degree of movement
Conventional emulsion surface treatment	< 50	Low
Modified emulsion surface treatment*	< 100	Medium

* Based on a 5% SBR content (latex).

12.8 DUST PALLIATIVE

Large amounts of dust are created by vehicles on unpaved roads. This is one of the reasons for the accident rates on unpaved roads being significantly higher than those on surfaced roads.

The use of emulsions as dust palliatives is a practical and economical solution to this problem. Diluted stable-grade anionic or cationic emulsions are sprayed directly onto the unpaved road surface.

The emulsion is diluted by the addition of five or more parts of water. This diluted emulsion is applied at a rate of 0,45 to 2,25 litre/m². The actual rate of application depends on the condition of the existing surface.

13. REHABILITATION

13.1 BACKGROUND

In recent years the emphasis has shifted from the construction of new roads to the rehabilitation of existing roads. Recycling of materials which have already served their original-intended purpose is often a cost-effective way of rehabilitating existing pavements.

13.2 RECYCLING

A wide range of pavement materials can be recycled, such as asphalt, cemented materials and granular materials. When emulsions are used in the recycling of asphalt, heating is not required as in the case of hot-mix recycling. Central plants may be used to recycle asphalt, using a cold mixing process; however, in-situ mixing is generally more economical.

13.3 APPLICATION OF GEMS

GEMS include the use of recycled pavement materials (see section 5).

The following design approaches are recommended when recycled pavement materials are used:

- recycled asphalt - stabilisation approach;
- recycled cemented materials - modification approach;
- good-quality recycled granular materials - modification approach; and
- moderate and poor quality granular materials - stabilisation approach.

13.4 MULCH TREATMENT

Soil erosion caused by water and wind can be a serious problem in the construction of embankments and on flat areas next to highways. The most common method of combatting this problem is by the use of vegetation to stabilize these areas. However, the seeds planted are susceptible to being blown or washed away.

A layer of stable grade anionic or cationic emulsion sprayed directly on the seeded area will form a thin membrane. This thin membrane offers the following benefits:

- the bitumen film holds the seeds in place and prevents their loss by the eroding forces of water and wind;
- because of its dark colour, the bitumen absorbs and holds solar heat during the germination period; and
- the bitumen film tends to hold moisture in the soil, thereby promoting faster plant growth.

When the young shoots break through the surface of the soil they can easily penetrate the thin bitumen film. This bitumen film disintegrates as the seedlings mature and cover the ground area.

There are other mulch treatment approaches, such as using straw and hay in combination with seeds, water and fertilizer.

14. REFERENCES

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APPENDIX A:
MIX DESIGN APPROACHES FOR GEMS

A1: Practical guidelines for mix design approaches for GEMS

The purpose of this appendix is to provide practical guidelines for the design of GEMS. The use of the dynamic indirect tensile test during the mix design process requires that these designs should be fully or partially conducted at facilities where this test method is available (e.g. CSIR, some universities and some commercial laboratories). Because of the manufacturing and curing time constraints, it is recommended that whenever engineering tests are conducted, the samples should be prepared and cured at the same facility.

However, as the method also requires standard and routine test methods, e.g. CBR and Marshall methods, these tests could be conducted at routine laboratories if preferred.

For planning purposes, both the stabilized and modified mix design approaches can be divided into three phases, namely:

- Phase I: Determination of fluid content
- Phase II: Determination of empirical properties (e.g. Marshall stability and CBR)
- Phase III: Determination of engineering properties (e.g. resilient modulus).

The tables below provide guidelines on the type of laboratory required for each phase of the design and estimates of the amount of material required.

Care should be taken to ensure that all the materials used in the design stage are representative of the materials to be used during construction.

Table A1: Material requirements for the design of stabilised GEMS

Design phase	Conducted by whom	Material requirements		
		Aggregate	Emulsion	Lime/Cement
I	routine or advanced	25 kg	2,5 litre	-
II	routine or advanced	25 kg	2,5 litre	1 kg
III	advanced only	20 kg	2,0 litre	1 kg

routine = routine and commercial laboratories

advanced = CSIR, some universities and commercial laboratories with specialised equipment

Table A2: Material requirements for the design of modified GEMS

Design phase	Conducted by whom	Material requirements		
		Aggregate	Emulsion	Lime/ Cement
I	routine or advanced	80 kg	8,0 litre	-
II	routine or advanced	120 kg	12,0 litre	4 kg
III	advanced only	25 kg	2,5 litre	1 kg

routine = routine and commercial laboratories

advanced = CSIR, some universities and commercial laboratories with specialised equipment

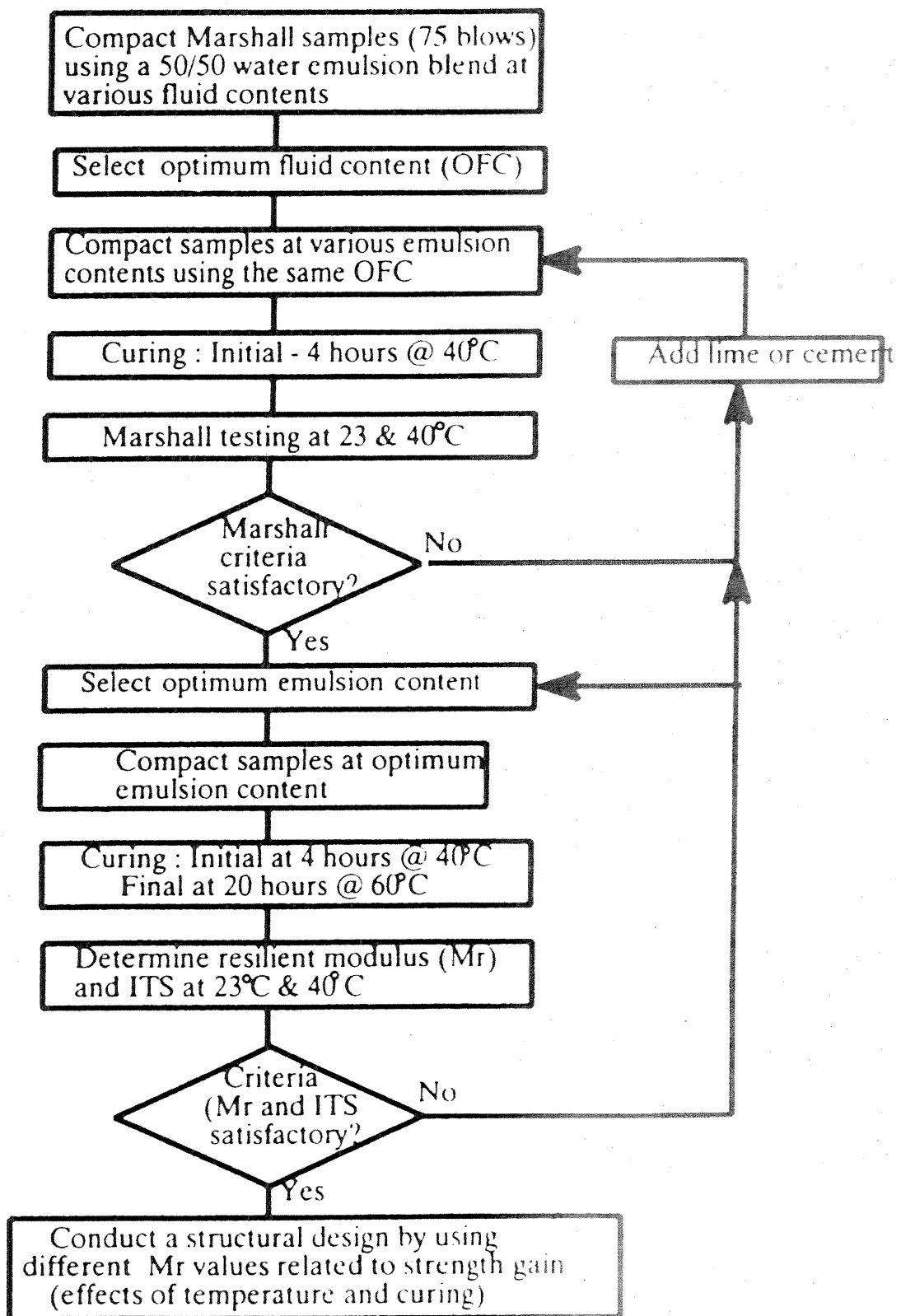


Figure A1: Outline of stabilised design approach

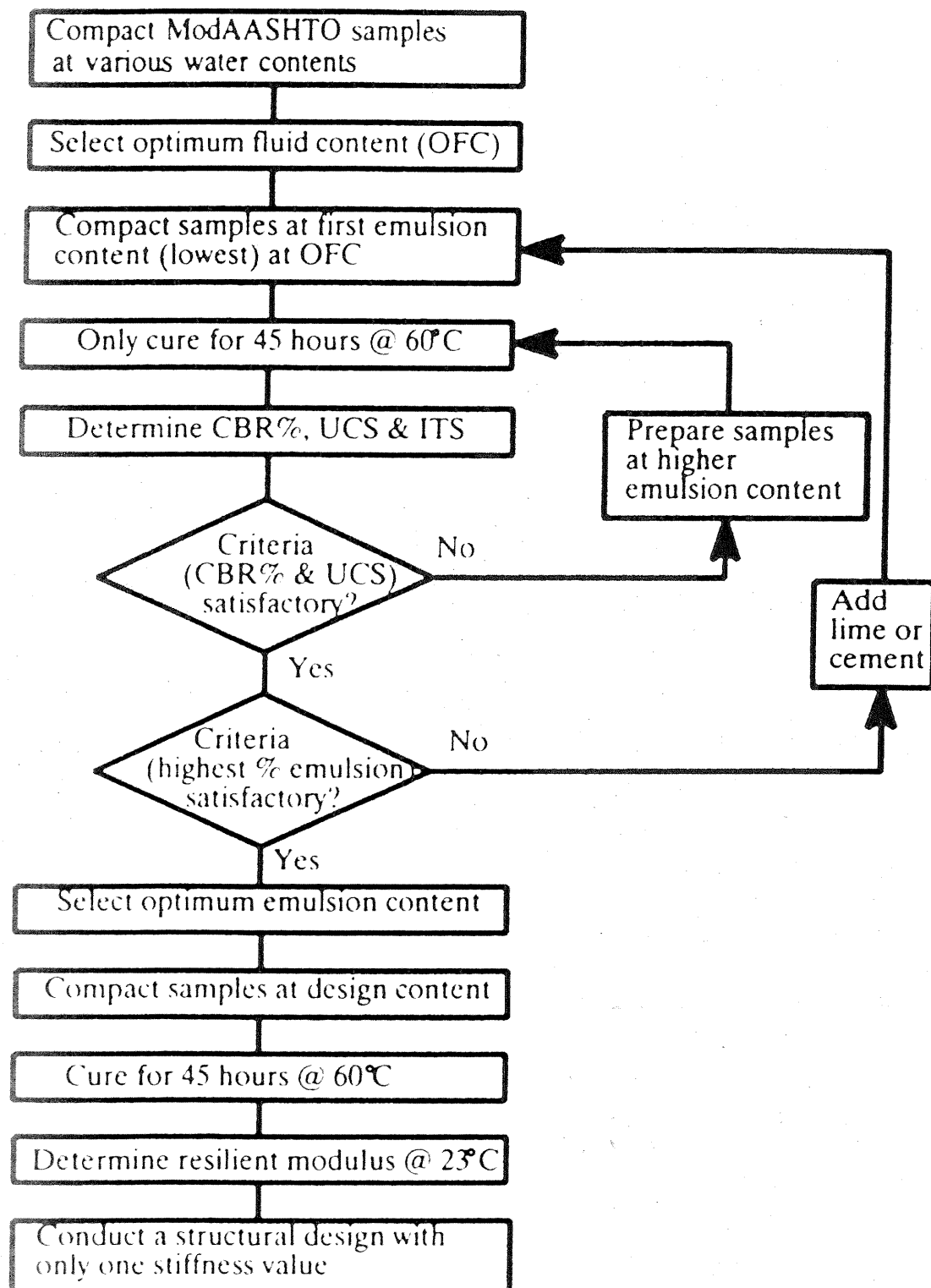


Figure A2: Outline of modified design approach

APPENDIX B:
AGGREGATE GRADINGS FOR USE IN SURFACE TREATMENTS

Table B2: Properties of grade 3 single-sized aggregate

Sieve size (mm)	Nominal stone size (mm)		
	13,2	9,5	6,7
	Cumulative percentage passing		
19,0	100		
13,2	85-100	100	
9,5	0-50	85-100	100
6,7	0-10	0-50	85-100
4,75		0-10	0-50
2,36			0-10
Fines content (< 0,475 mm)	2,0		3,0
Dust content (< 0,075 mm)	1,5		
Flakiness index (max)	30	35	

Table B3: Grading requirements for fine slurry

Sieve size (mm)	Cumulative percentage passing
4,75	100
2,36	90 - 100
1,18	65 - 95
0,6	42 - 72
0,3	23 - 48
0,15	10 - 27
0,075	4 - 12

Table B4: Grading requirements# for rapid-setting polymer-modified coarse slurry

Sieve size (mm)	Cumulative percentage passing	
	Type 1	Type 2
13,2		100
9,5	100	85 - 100
6,7	85 - 100	70 - 90
4,75	70 - 90	60 - 80
2,36	45 - 70	40 - 60
1,18	25 - 45	25 - 45
0,6	15 - 30	15 - 30
0,3	10 - 20	10 - 20
0,15	6 - 15	6 - 15
0,075	4 - 10	4 - 10

Other proven gradings may also be acceptable e.g. the grading recommended by the International Slurry Surfacing Association.