

CHAPTER 2 MIX DESIGN AND ENGINEERING PROPERTIES OF EMULSION TREATED MATERIALS

2.1 INTRODUCTION

This chapter contains a literature review of mix design methods and the properties of emulsion treated mixes. Mix design has an influence on the structural properties and –design of emulsion treated pavement layers. Only aspects of mix design that have an influence on the structural properties, structural behaviour and structural design of emulsion treated layers will be reviewed.

2.2 HISTORY AND BACKGROUND OF EMULSION TREATED MATERIAL MIX DESIGN

Bitumen emulsion was initially added to granular materials to improve the water resistance of materials, to serve as a compaction aid and to improve the durability of the base layer if opened to traffic soon after construction (Horak et al: 1984). No formal design procedure was available at that stage and the designs relied on the experience and judgement of the engineer. Kari (1969) published a mix design procedure for emulsion treated materials to prevent permanent deformation. Three laboratory tests were adopted, namely:

- Moisture-vapour-susceptibility (mvs) test: This test subjects the emulsion treated base to the damaging effects of water in the vapour state.
- Resistance R-value test: This test provides an index of shear strength of the mix after exposure to water vapour.
- Cohesimeter C-value test: This test is an index of mix tensile strength and is used to evaluate the extent of cohesion failure and stripping of the mix after exposure to water vapour.

Spottiswoode (1979a) presented results from a study where the mix design of emulsion treated materials was based on CBR and UCS tests. Because low percentages of bitumen were added, it was anticipated that the emulsion treated materials would exhibit properties closer to granular or cemented materials than bituminous materials, hence the use of CBR and UCS tests. He presented the influence of density, curing and temperature on the UCS and CBR (Spottiswoode: 1979b).

Marais and Tait (1989) published proposals on emulsion treated base mix design in 1989. They view the following properties critical to the design:

- Initial shear strength to prevent deformation in the base layer under traffic and varying environmental temperature conditions.
- Permeability to ingress of subsoil water

- Brittleness

They suggested that the Marshall method should be modified to accommodate the particular characteristics of emulsion treated materials. It was proposed that the properties of the treated layers be evaluated at higher temperatures to ensure that under summer conditions and at an early cured state, it will not deform under the action of traffic.

Other mix design methods for emulsion treated materials are described by Louw (1996) and include the following:

- Modified Hveem method (similar to method described by Kari (1969))
- Asphalt Institute
- Retread method
- Abecol method
- Chevron method
- Illinois method, and
- Texas triaxial test method

In 1993 SABITA published the GEMS manual (SABITA: 1993) where formal mix design methods are described for granular materials treated with bitumen emulsion. The publication was based on a research project sponsored by SABITA. The research included extensive laboratory testing and evaluation of the mixes in the field by Heavy Vehicle Simulator testing.

2.3 EMULSION TREATED MATERIAL MIX DESIGN IN SOUTH AFRICA

The SABITA manual 14 (SABITA: 1993), distinguishes between a modification and stabilisation approach in mix design. The modification approach applies to materials with net bitumen contents of less than 1.5 % by mass of the dry aggregate, while the stabilisation approach applies to materials with more than 2 % net bitumen by mass. The binder content between 1.5 % and 2 % is considered to be a “grey” area where either the modification or stabilisation approach might be applicable. The quality of the parent material should play the decisive role in this case.

In 1999 the SABITA manual 21 (SABITA: 1999) was published. It provides clear guidelines on mix design for the modification approach.

The definitions *modification* and *stabilisation* described in this study and in SABITA manuals 14 and 21, differs from the commonly used definitions where *modification* implies the alteration of the physical properties of a material, while *stabilisation* implies the chemical alteration of a material.

2.3.1 Mix design for the stabilisation approach (net bitumen > 1.5 %)

A formal mix design method for materials with net bitumen contents in excess of 1.5 % are recommended in SABITA manual 14 (SABITA: 1993). The document is based on the research initially conducted by Marais and Tait (1989). The purpose of mix design is to determine the correct composition of components and to provide design parameters for the structural design. SABITA manual 14 provides guidelines on emulsion, aggregates, lime and cement and curing.

The optimum binder content is determined by using the Marshall method on samples prepared with different residual bitumen contents. A minimum stability of 2.2 kN at 23°C is required while the stability at 40°C should not be less than 1 kN.

Indirect tensile strength (ITS), carried out at 23°C and 40°C, at a loading rate of 50 mm/min, should not be less than 100 kPa, and if exposed to water, not less than 50 kPa. The ITS is not normally used to determine the optimum binder content.

The stiffness (E-value) of the material could be determined by the methods recommended in SABITA manual 14. The E-value should not be less than 1 000 MPa at 23°C.

Voids should be less than 15 % to prevent excessive strength loss due to water ingress and not less than 5% to allow the emulsion to break and cure.

2.3.2 Mix design for the modification approach (net bitumen < 2.0 %)

A design method for the modification approach was recommended in SABITA manual 14, but after additional research (Louw: 1996, Louw: 1997, Verhaeghe: 1998a and Verhaeghe: 1998b) it was replaced by the method recommended in SABITA manual 21 (SABITA: 1999). A schematic overview of the mix design for the modification approach is presented in Figure 2.1.

Materials with low percentages of bitumen (less than 2%) can hardly be described as visco-elastic and their behaviour will primarily be similar to that of treated gravels. The use of the Marshall method is therefore not realistic and the materials should rather be characterised in terms of CBR and UCS. SABITA (1999) recommends, after research by Verhaeghe (1998b), that 1% cement should be added to assist in the breaking process and adhesion of the emulsion, and to increase the early strength development where the layer is to be opened to traffic soon after construction. The effect of cement on a G4 material is illustrated in Figure 2.2.

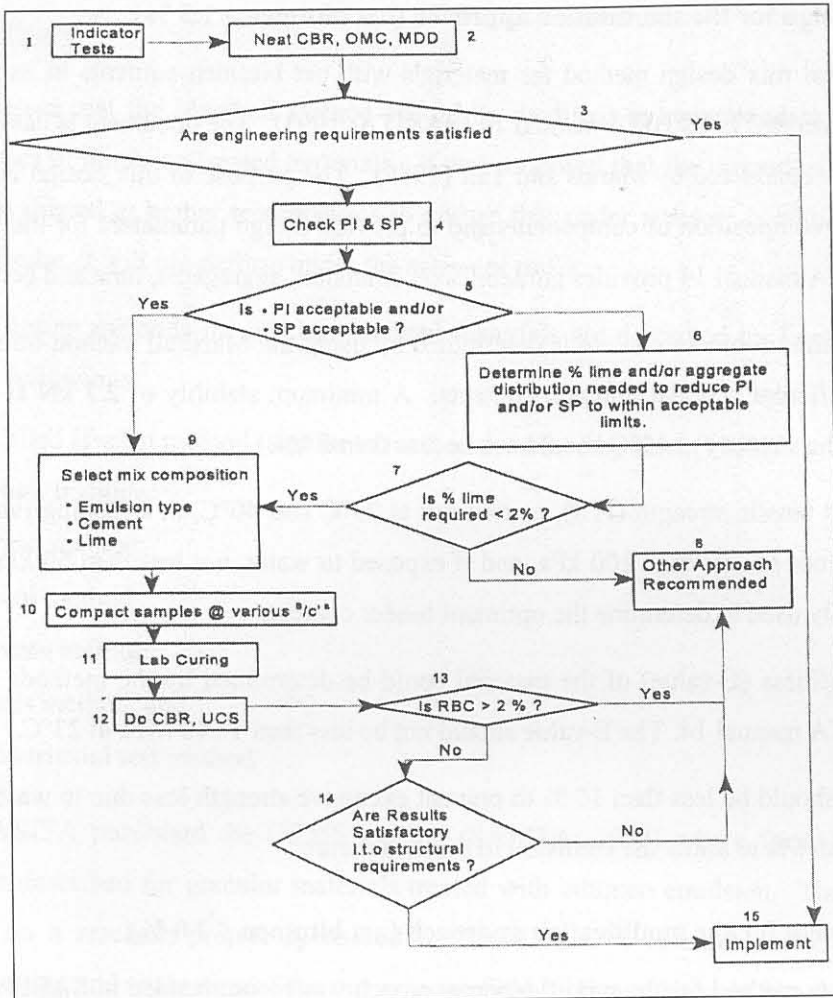


Figure 2.1 Schematic overview of the ETB mix design process (Verhaeghe: 1998a)

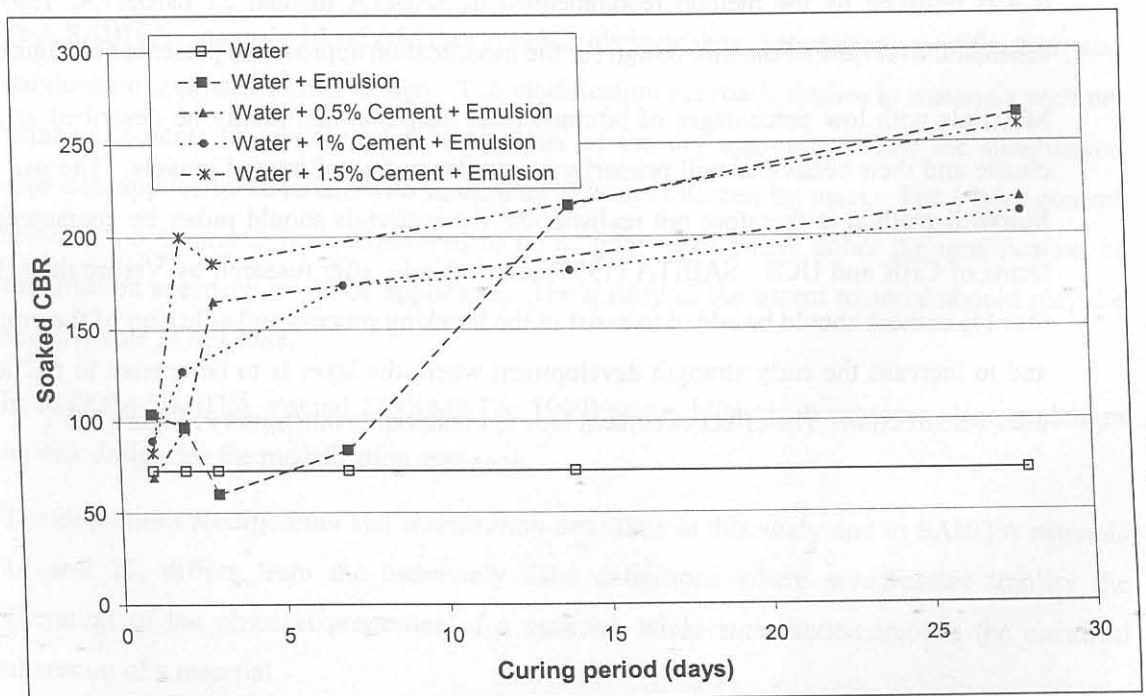


Figure 2.2 Effect of cement content on CBR for G4 material (Verhaeghe: 1998b)

The optimum bitumen content is determined by CBR and/or UCS testing on samples with different residual bitumen contents. The mix design criteria for emulsion treated materials according to the modification approach are outlined in Table 2.1. No ITS tests are being recommended in the modification approach.

Table 2.1 Mix design criteria for ETB's in terms of CBR and UCS (SABITA: 1999)

Material Code	Minimum CBR	Minimum UCS
E1	150 at 100% mod. AASHTO compaction	1 200 kPa
E2	100 at 100% mod. AASHTO compaction	750 kPa

2.4 THE ENGINEERING PROPERTIES OF EMULSION TREATED MATERIALS

As with other road building materials, the engineering properties of emulsion treated materials should be taken into account during the structural design process. The important engineering properties are:

- Stiffness
- Resistance to fatigue cracking
- Resistance to permanent deformation
- Durability

The curing of emulsion treated materials has a major influence on the stiffness of the layer in its early life (up to the first two years). The failure mechanism will therefore be dictated by the stiffness state of the emulsion treated layer during that period. Permanent deformation or fatigue cracking may initially be the prominent failure mechanism, with shear deformation or fatigue cracking dominant thereafter. This needs to be properly defined to develop a structural design model.

2.4.1 Stiffness and resilient modulus

The stiffness of the pavement layer is an important aspect of the structural design. Stiffness of emulsion treated layers depends on the following:

- Curing
- Temperature (more important for higher bitumen contents)
- Rate of loading (more important for higher bitumen contents)

Kari (1969) made use of dynamic triaxial tests to determine the resilient modulus from the following expression:

$$M_R = \frac{\sigma}{\varepsilon} \quad (2.1)$$

where M_R = Resilient modulus

σ = applied axial (deviator) stress

ε = resilient (recoverable) axial strain

He reported values between 60 000 psi (410 MPa) and 900 000 psi (6 200 MPa) with an average value of 300 000 psi (2 000 MPa). It was noted that the upper values approach that of values typical for hot mix asphalt at 77°F (25°C). An increase in relative density of as little as 8% resulted in an increases in excess of 90% for resilient modulus, while curing after 28 days resulted in a 25 % increase in resilient modulus.

Kari (1969) proposed the following empirical relationship to estimate the field resilient modulus:

$$\ln(M_R * 10^{-3}) = 0.4\rho + 2.46S - 0.15Pen \quad (2.2)$$

where: M_R = Resilient modulus (psi)

ρ = density in lb/cu.ft

S = Sand fraction (#4 (4.72 mm) to minus 200 mesh (75 μ m))

Pen = Penetration of recovered bitumen at 77°F (25 °C)

He reported a reasonable fit from the empirical data and adequate for estimating purposes.

Santucci (1977) indicated that the ultimate design modulus might be reached after six months to two years depending on the climate.

According to Marais and Tait (1989) the resilient modulus may be estimated from Indirect Tensile Strength by Equation 2.3, if equipment to determine the modulus accurately is not available.

$$M_R = 5.123 * ITS - 75 \quad (2.3)$$

where: M_R = Resilient modulus in MPa

ITS = Indirect Tensile Strength in kPa at 23°C

SABITA (1993) proposes the following relationship between stiffness and CBR for estimation purposes:

$$E = k.CBR \quad (2.4)$$

where: E = Stiffness in MPa

CBR = California Bearing Ratio (%) at the required compaction

k = constant: 5 for G1 and G2 parent materials

6 for G3 and G4 parent materials

7 for G5 parent materials

De Beer and Grobler (1994) reported values for elastic moduli of 800 MPa after construction to values of approximately 3 000 MPa after 10 months. The highest rate of increase in stiffness was observed between three to four months after construction. Indirect Tensile Strength values also increased from around 300 kPa to approximately 900 kPa.

A reduction of the elastic moduli of approximately 50% was reported by de Beer and Grobler (1993) after 10 000 to 20 000 repetitions by the Heavy Vehicle Simulator at various wheel loads. This can be attributed to the development of fatigue cracks within the emulsion treated layer.

2.4.2 Resistance to fatigue cracking

Repeated loading progressively reduces the tensile strength of emulsion treated materials. Fatigue resistance increases as the emulsion content increases. It is however not as sensitive to bitumen content as asphalt mixes. Small variations will not have a big influence on the fatigue properties. Fatigue characteristics are not generally measured for design purposes according to the SABITA manual 14. (SABITA: 1993). Experiments on road S12 between Witbank and Johannesburg by Marais and Otte (1979), showed that after 9 years and approximately 3.5 million E80's, no cracks were visible on the surface of the section treated with emulsion. Only one other section constructed with other pavement materials could match this performance.

2.4.3 Resistance to permanent deformation

Permanent deformation is the result of the accumulation of repeated plastic strains due to traffic loading. It is caused by a combination of consolidation and shear movement. Proper compaction prevents consolidation to a large extent, while shear deformation could be minimised by proper mix design. Emulsion treated layers are sensitive to permanent deformation in its early life, mainly because of the fact that the curing process is not completed. Once curing has been more or less completed, permanent deformation is rarely the primary

mode of failure (Marais and Otte: 1979). The addition of cement greatly prevents the early sensitivity to permanent deformation.

2.4.4 Durability

Bitumen emulsion was first used in South Africa to allow traffic on the finished base layer soon after construction to reduce or prevent ravelling (Bergh: 2001). This proved to be successful with a minimum disruption to traffic. Emulsion treated materials show greater resistance to the damaging effects of water in the layer than granular or cemented material. (SABITA: 1993, SABITA: 1999). Maree et al (1982) reported that four times less fines were brushed off during a brushing durability test, compared to untreated material. Horak et al (1984) found that the rate of permanent deformation did not change with the addition of water into a pavement recycled with a bitumen emulsion base layer.

Tests done by Spottiswoode (1979a) indicated that the permeability of the material is reduced by the addition of emulsion at high compaction (100 % mod. AASHTO). Horak et al (1984) measured permeability that was three to five times higher than for good compacted crushed stone layers.

2.5 CURING OF EMULSION TREATED LAYERS

The ultimate stability and related properties (stiffness, etc.) of emulsion treated materials are not reached until a major portion of the water in the material has evaporated. Under field conditions this may take several months, or even up to two years (Louw: 1996).

Curing is important to prevent permanent deformation in the early part of the life of an emulsion treated layer. Smaller amounts of emulsion will require shorter periods for full curing, but the length of curing is mainly influenced by the climatic region. Wetter climatic regions will result in slower curing while curing in dry climates may be substantially faster. The addition of lime or cement can assist in the speeding up of the curing process. Lime or cement acts as a catalyst to enhance the breaking process and uses the free water in the material.

Louw (1996) indicated that approximately 70% of the strength of emulsion treated layers is gained within the first two weeks, and that the increase in strength after 18 months is minimal.

2.6 CONCLUSIONS

The following conclusions, which are of importance in the structural design process, can be drawn from the literature study on mix design and engineering properties of emulsion treated materials.

- Mix design processes for emulsion treated materials are well researched, documented and established. The need is for a mechanistic structural design method that will enable

design engineers to bring together the principles of pavement design and the outputs available from the mix design processes.

- The failure mechanism of emulsion treated materials is dependant on the state of curing of the material. Young uncured layers could accumulate permanent deformation that would result in excess rutting, while cured layers could fail in fatigue and/or shear.
- Emulsion treated materials provide better resistance to fatigue cracking than cemented layers. An emulsion treated layer can withstand more elastic movement before failure occurs.
- The increased durability of emulsion treated materials makes it less sensitive to water and has the advantage that an emulsion treated layer may be opened to traffic, for a limited period of time, soon after construction without an overlay or seal.
- Curing of emulsion treated materials is an important aspect to ensure proper strength development and the addition of lime or cement may assist in early strength development.

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