

Evaluation of Cement and Bitumen Emulsion on Strength Characteristics of Native South African Granular Soil as Base Course Material

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Abstract— Pavement rehabilitation where the material in the existing pavement is recycled in-situ with bitumen will sustain the environment with conservation of natural aggregates, reduction in noise, dust emission and traffic disruption. This study investigate the effects of a native South African granular material stabilized with cement and bitumen emulsion as a base layer in pavement construction. The material stabilized with cement-bitumen emulsion (2-3%) was subjected to Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) tests for 1, 4, 7 and 28 days curing. The UCS and ITS requirement was evaluated with respect to a base layer for design traffic application of less than six million equivalent single axles. The results of UCS and ITS tests for the stabilized material showed improved strength and have the potential for use as a base course material for the design traffic. The result revealed that 2.5% cement and bitumen emulsion meets the minimum strength characteristics for the base layer. Relative to 2% cement and 2% bitumen emulsion, ITS obtained for 4 and 7 days of curing increased approximately by 24%, 41% and 24%, 53% respectively. Models for UCS in terms of ITS was developed for cement and bitumen emulsion which will make one test among the two sufficient to indicate the strength of cement and bitumen emulsion stabilized materials at the mix design level. Bitumen stabilization is a quick construction method, with lower cost than reconstruction and good for rehabilitation.

Keywords— bitumen emulsion, cement, granular, indirect tensile strength unconfined compressive strength.

1 INTRODUCTION

Highway pavements constructed with bitumen stabilized materials (BSMs) using either bitumen emulsion or foamed bitumen are environmentally sustainable (Baghini *et al.*, 2015; Giani *et al.*, 2015; Motta *et al.*, 2014; Chiu *et al.*, 2008). BSMs are suited for both constructions of new pavement and pavement rehabilitation. BSMs are non-continuously bound materials that fall in a class of their own. They are granular materials treated with small amounts of bitumen emulsion or foamed bitumen (usually < 3% residual bitumen, by mass) and active filler (< 1% cement or lime by mass) that significantly increases the cohesion of the materials whilst having little effect on the angle of internal friction (Asphalt Academy, 2009; Ebels & Jenkins, 2007; Collins & Jenkins, 2011). When used to construct a pavement layer, a BSM behaves more like an unbound granular material than one that is continuously bound, as would be achieved had cement been used as the stabilizing agent. The addition of bitumen emulsion or foamed bitumen to produce a BSM results in an increase in material strength and reduction in moisture susceptibility as a result of the manner in which the bitumen is dispersed amongst the finer aggregate particles (Lewis & Collins, 1999; Collins, 2009).

Adrian Bergh is credited to have used bitumen emulsion in South Africa in the 1970s to address premature failures on the infamous N12 highway. Over 40 years later, some of those sections are still performing well (Collins & Thompson, 2007). Bitumen emulsion was also used to stabilize in situ Aeolian dune sand on low volume roads in the region of Northern KwaZulu-Natal, after 17 years of service; this road is still providing the only access to Sodwana Bay in spite of minimal maintenance (Paige-Green & Ware, 2000).

Marandi and Safapour (2009) analyzed the effect of cement and bitumen emulsion on base course modification in comparison with the conventional pavement and possible use in regions with low quality materials. Optimization of cement and bitumen emulsion was carried out using Indirect Tensile Strength (ITS), Unconfined Compressive Strength (UCS) and Marshall Stability tests after 7 and 28 days of curing. The result showed that using 3% for both optimized stabilizers improves the stiffness and elasticity of the observed pavement after one year of construction. The study on strength and compaction characteristics of bitumen stabilized granular soil showed that the optimum binder content required to achieve optimum Maximum Dry Density and (MDD) and California bearing ratio (CBR) was 4% (Ogundipe, 2014).

Huan *et al.*, (2010) evaluated four different aggregate mixtures treated with three different foamed bitumen contents compacted with 1% hydrated lime at 100% optimum moisture content and cured for 7 days at room temperature. A mixture consisting of 75% crushed rock base and 25% crushed limestone showed the best performance in terms of indirect tensile strength and unconfined compressive strength values when treated with 3% foamed bitumen. Soil stabilization utilizing cement and bitumen emulsion in improving the soil properties was reported by Baghini *et al.*, (2013a), 164 samples with different percentages of cement and bitumen emulsion were mixed with soil aggregates, by examining the UCS and modulus of elasticity on samples. The findings revealed that the optimum values of cement and bitumen emulsion in improving the soil was both 3%. Improving the bearing capacity of Black Cotton Soil (BCS) was carried out using bitumen emulsion and sea shell powder. The bitumen emulsion was added at a proportion of 20 to 26% and sea shell at 12 to 18% at an increment of 2% in the dry weight of the soil. Optimum UCS of the stabilized BCS was achieved

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at 24 and 16% for bitumen emulsion and sea shell respectively (Jayaganesh *et al.*, 2012). Other authors (Baghini *et al.*, 2013b; Grilli *et al.*, 2012; Bocci *et al.*, 2011; Perez *et al.*, 2013; Kavussi & Modarres, 2010a & 2010b) have worked on marginal soils or in situ materials blending and mixing Portland cement and/or bitumen emulsion to enhance the strength, durability and pertinent properties of the soil. The purpose of this study is to evaluate cement and bitumen emulsion in enhancing the strength characteristics of natural granular soil as base course material for pavement construction. This paper presents laboratory tests to evaluate the effect of adding cement and bitumen emulsion on the geotechnical properties of the granular soil in terms of grain size distribution, Atterberg limits, compaction characteristics, UCS and ITS. In addition, optimum content of cement and bitumen emulsion on the granular soil was determined as well as comparing the effect of the additives on the mixtures using significant models.

2 MATERIALS AND METHODS

Soil material was sampled randomly from twelve locations along Main road MR 279 near Villiersdorp Western Cape, South Africa and is described as a light reddish orange sand stone. Guidelines and mode of evaluation in testing methods for highways and materials as stipulated in the specification were followed in determining the geotechnical characteristics of the soil material (SANS, 50450-1, 2011; SANS, 55167-1, 2011; TMH 1, 1986). The soil samples were air-dried, divided equally by means of a riffler (TMH 5), sieved through a series of sieves and materials retained on 0.425 mm sieve were used for the Atterberg limits and result summarized in Table 1. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) was determined using modified Association of American Highway and Transportation Official (AASHTO) relative density method for both the virgin and modified soil materials.

The active filler (CEM-II B-M 32.5) was limited to 1% for bitumen emulsion stabilized material as recommended by the Asphalt Academy (2009:32), was spread over the soil and mixed in blender-type laboratory mixer. It helps the bitumen stabilized material to improve the adhesion of the bitumen to the aggregate and dispersion of the bitumen in the mix. Anionic stable grade bitumen emulsion was introduced at a rate of 2.0, 2.5 and 3.0% of the mass of the material, when mixed the bitumen droplets are attracted to the granular particles. Cement at 2, 2.5 and 3% was used to stabilized the granular soil for comparison with bitumen emulsion. All the mixtures were compacted at optimum moisture content to 100% modified AASHTO using vibratory hammer compaction. Two curing regimes are required for bitumen stabilized specimens, the specimens are initially placed in a draft oven at 30°C to allow the moisture to reduce, then sealed in plastic bags and cured at 40°C for 48 hours if the optimum moisture content of the sample is less than 8% and if more than 8% at 60°C for 45 hours (Asphalt Academy, 2009). Cement stabilized specimens were kept in humidity room until testing. Three briquettes each of the mixed samples were used to

perform UCS and ITS tests at 1, 4 and 28 days. The briquettes were soaked in water for 6 hours before testing for UCS. The ITS test was used as an indirect measure of the tensile strength and flexibility of the BSM to reflect the flexural characteristics of the material. The UCS and ITS requirements are related strongly to the number of equivalent axles, for this study a base layer for design traffic applications of less than six Million Equivalent Single Axles was adopted as a result of the source material (Table 2).

Table 1. Particle Aggregates Distribution, Atterberg limits and grading specification for the mixture

Sieve Size	Virgin Soil	2% cem	2.5% cem	3% cem	1%ce m +2% bit	1%ce m +2.5 % bit	1%ce m + 3% bit	Spe cific atio n
53.0	100	100	100	100	100	100	100	100
37.5	95	96	95	94	97	96	95	87-100
26.5	83	84	82	83	85	83	84	77-100
19.0	77	80	77	75	81	78	76	66-99
13.2	71	73	72	69	74	72	70	67-87
4.75	51	52	50	51	49	47	45	36-56
2.00	41	41	40	43	36	35	33	25-42
0.425	27	27	26	29	21	19	18	10-24
0.075	6	4	3	3	3	2	1	2-9
GM	2.26	2.28	2.31	2.25	2.40	2.44	2.48	
LL	16	-	-	-	-	-	-	
PI	2.1	NP	NP	NP	NP	NP	NP	
LS	0.4	-	-	-	-	-	-	
AASH	A-	A-	A-	A-	A-	A-	A-	
TO	1-a	1-a	1-a	1-a	1-a	1-a	1-a	
MDD	213	203	203	202	202	201	200	
	6	8	0	1	1	9	5	
OMC	7.0	7.8	7.6	8.0	8.0	7.9	7.8	
CBR	46	-	-	-	-	-	-	

Table 2. Specification for Bitumen Stabilized Materials (Asphalt Academy, 2009)

Level mix design	Material	Design traffic (106)	UCS (MPa)	ITS (kPa)	CBR (%)	PI (%)	0.075 (%)
BSM 1	Well graded Crushed stone	6	1.2-3.5	> 225	> 80	< 10	4-15
BSM 2	Natural gravel	< 6	0.7-1.2	175-225	25-80	6-12	5-25
BSM 3	Soil-gravel or Sand	< 1		125-175			

3 RESULTS AND DISCUSSION

The particle size distribution of aggregates for different mixes were as listed in Table 1, and all were within the acceptable limits for bitumen emulsion stabilization. From the experimental data, Figure 1 shows the relationship between cement and bitumen emulsion content and MDD. There is a decrease in MDD both for cement and bitumen content increases compared to the

virgin material. This result was contrary to Baghini *et al.*, (2015) work on base course material treated with cement, bitumen emulsion and cement-bitumen emulsion. The OMC for all the specimens were in the range of 7.0-8.0%.

based on the experimental data. Addition of bitumen and active fillers to the granular materials results in an increase in shear strength, flexibility and resistance to moisture damages. Such increase in shear properties empowers the layer made of BSMs to withstand higher stresses from the heavy truck loads.

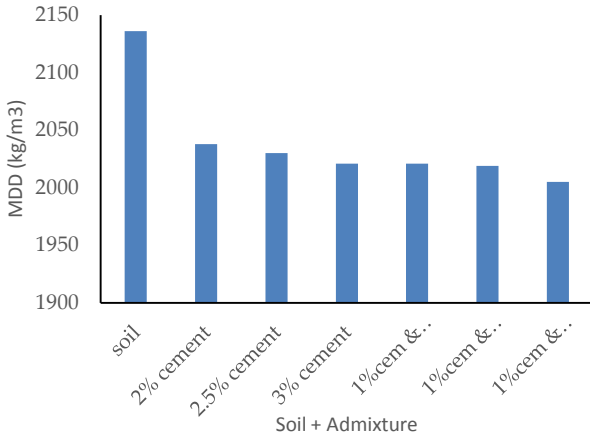


Fig. 1: Plot of MDD against Cement and Bitumen emulsion

3.1 INFLUENCE OF CEMENT AND BITUMEN EMULSION ON UCS OF STABILIZED SOIL

The variations of UCS for the stabilized soil with cement and bitumen emulsion are presented in figures 2-5 respectively. Figure 2 shows the effect of the cement content on the UCS of the mixture for 1, 7 and 28 days of curing. Previous studies have shown that the behavior of pavement layers constructed from BSMs falls between rigidity and visco-elasticity. The experimental data were fitted into logarithmic models, showing the relationship between these parameters. An increase in cement causes an increase in the UCS of the mixture on the account of the hydration products of the cement thus enhancing the rigid bonds within the soil-aggregate. The bitumen-emulsion has environmental benefit particularly positive when used for in-place or on-site techniques that avoid the energy usage and emissions associated with cement. In addition, bitumen emulsion pavement increases the construction speed, enhances the structural integrity of the pavement and in some cases reduce the overall time project. A stiffer base reduces deflections due to heavy traffic loads, thus extending pavement life. From the figure and the minimum strength requirement for Level 2 listed in Table 2, the optimum cement content was at 2.5%. The influence of bitumen emulsion content on the UCS for 1, 4, and 28 days of curing is shown in figure 3. The 4-day is considered in the specification for UCS as well as ITS, it is seen that an increase in the bitumen emulsion content also resulted in an increase in UCS of the mixture. The minimum UCS specified was met at 2.5% bitumen emulsion content but less to cement at the same content which was relative to Baghini *et al.*, (2013b) and Tshivhase (2008) works on potentials of Portland cement and bitumen emulsion mixture on soil stabilization in road base construction. The relationship between UCS, curing time and bitumen emulsion content such as logarithm model and power model are expressed in Eq. 1-2 for 4 day of curing as specified

$$UCS = 454.9bit^{1.3764} \quad R^2 = 0.9901 \quad (1)$$

$$UCS = \ln(day) + 781.03 \quad R^2 = 1 \quad (2)$$

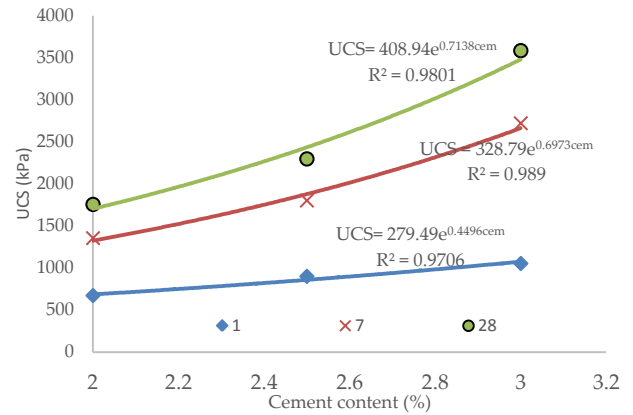


Fig. 2: Plot of UCS against Cement content

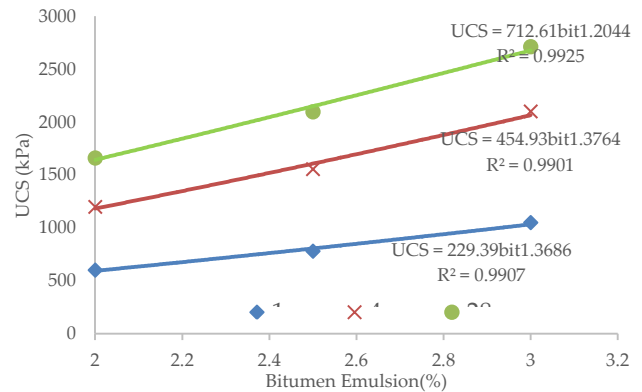


Fig. 3: Plot of UCS against Bitumen emulsion

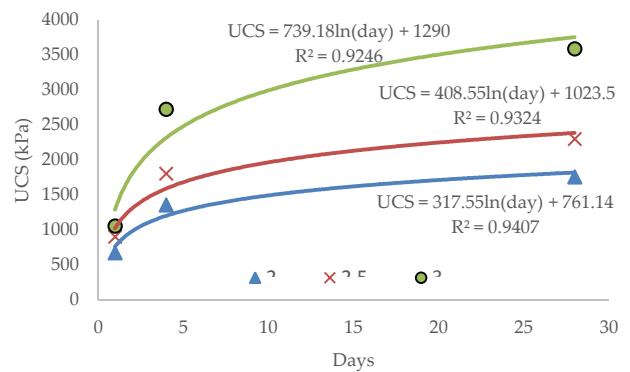


Fig. 4: Plot of UCS against Curing days for Cement

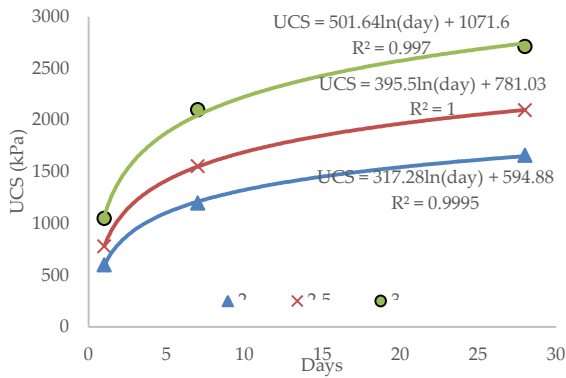


Fig. 5: Plot of UCS against Curing days for Bitumen emulsion

3.2 INFLUENCE OF CEMENT AND BITUMEN EMULSION ON ITS OF STABILIZED SOIL

The influence of cement and bitumen emulsion on the ITS of the mixture are summarized in figures 6-9. The results indicate that the ITS increases with increasing time for 2, 2.5 and 3% cement and bitumen emulsion contents confirming what has been reported in literature about the effect of active filler on the increase of fatigue resistance in bituminous mixture (Pasetto & Baldo, 2012; Ebels & Jenkins, 2007). Relative to 2% cement and bitumen emulsion, ITS obtained for 4 and 7 days of curing increased approximately 24%, 41% and 24%, 53% respectively. Based on the experimental data, the relationship between ITS and the mixture (bitumen emulsion and cement) are expressed in Eqns. 3-4 for 4-day and 7-day respectively.

$$ITS = 76.506e^{0.4222bit} \quad (R^2 = 1) \quad (3)$$

$$ITS = 209.75 \ln(cem) + 63.064 \quad R^2 = 0.9991 \quad (4)$$

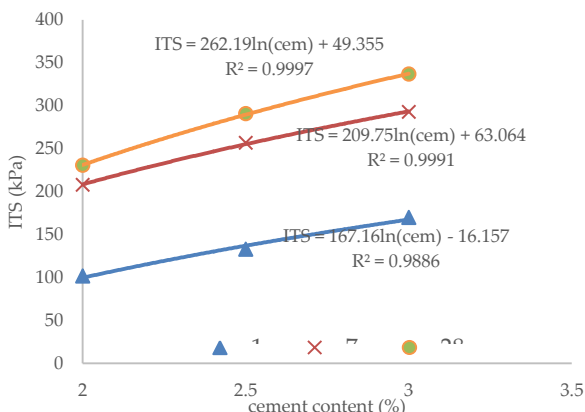


Fig. 6: Plot of ITS against Cement content

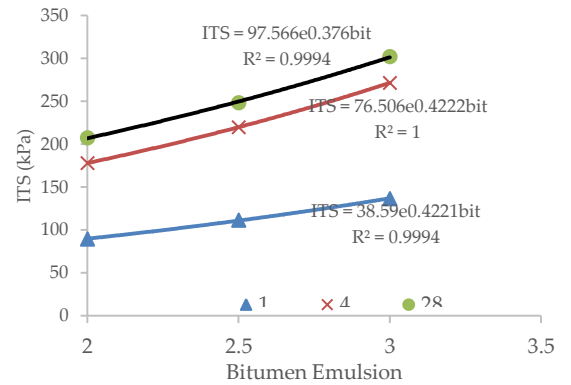


Fig. 7: Plot of ITS against Bitumen content

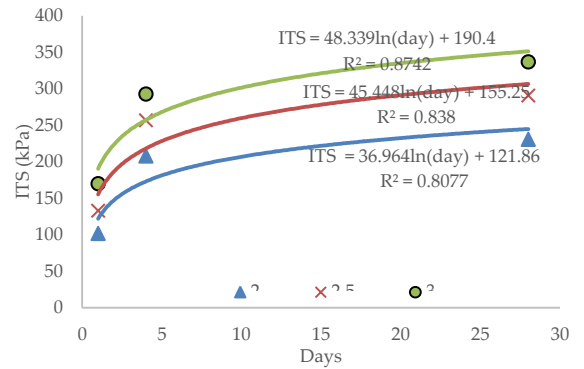


Fig. 8: Plot of ITS against the Curing days for Cement

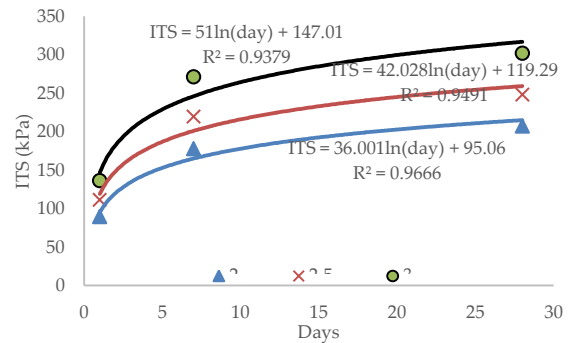


Fig. 9: Plot of ITS against Curing days for Bitumen emulsion

3.3 RELATIONSHIP BETWEEN UCS AND ITS FOR STABILIZED SOIL

Previous researchers had shown a relationship between the UCS and ITS for bitumen emulsion stabilized materials (Houston *et al.*, 2004; Nwando, 2013). The experimental data were analyzed in order to investigate if there could be relationship between these parameters. An exponential models fitted the data more than the linear for both mixture with cement and bitumen emulsion (figure 10). The models are expressed in Eqs. 5 and 6 respectively, moreover, one test among the two will be sufficient to indicate the strength of bitumen stabilized materials at the mix design level.

$$UCS = 368.01e^{0.0074ITS} \quad (5)$$

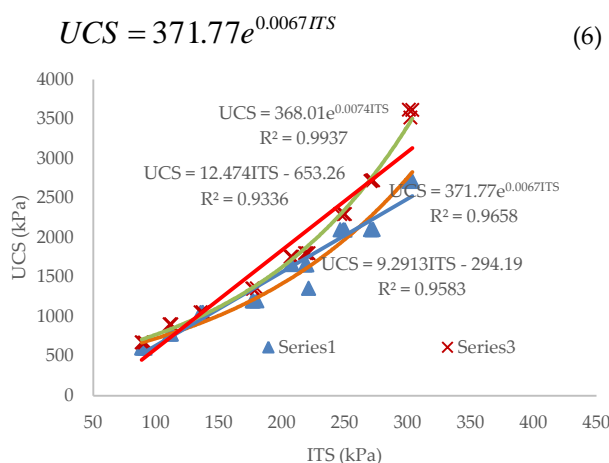


Fig. 10: Plot of UCS against ITS for Cement and Bitumen emulsion content

4 CONCLUSION

Analysis of the results of this study shows the following conclusions can be drawn:

- The virgin and treated materials falls under A-1-a category according to AASHTO classification and the results of OMC was used to adjust for the curing regime
- The granular soil modified with both cement and bitumen emulsion have excellent potential for use as a base course for traffic applications of less than six million equivalent single axles
- Based on the study findings, the use of 2.5% cement and bitumen emulsion in the base layer are recommended
- The results showed that the addition of both the cement and bitumen emulsion significantly increased UCS as well as ITS thus improving moisture resistance and durability compared to the virgin material
- Bitumen stabilization is a quick construction method and has a lower cost than reconstruction
- Layers made of BSMs have a rapid strength gain and can therefore be opened to traffic almost immediately after compaction
- The logarithm and power models between UCS, curing time and bitumen emulsion content were developed based on four days of curing based on the experimental data
- The ITS increases with increasing time for all the percentages of cement and bitumen emulsion considered thus confirming what has been reported in literature about the effect of active filler on the increase of resistance in bituminous mixture
- Relative to 2% cement and 2% bitumen emulsion contents, ITS obtained for 4 and 7 days of curing increased approximately 24%, 41% and 24%, 53% respectively
- Two models for UCS for the granular soil in terms of ITS was developed for cement and bitumen emulsion which will make one test among the two will sufficient to indicate the strength of the stabilized materials at the mix design level
- Bitumen stabilized materials is recommended for rehabilitation projects where the distress is confined to the upper layers

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