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Research Paper

COMPARISON OF SHEAR STRENGTH CHARACTERISTICS OF STONE MATRIX ASPHALT MIXTURE WITH WASTE PLASTICS AND POLYPROPYLENE

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The triaxial test measures the mix stability in shear strength and gave better information for field performance prediction. The stresses acting on the specimen simulate pavement stresses. The Stone Matrix Asphalt mixtures (SMA) are investigated using triaxial shear strength testing (50.8 mm/min ram rate loading at 60°C) to investigate the effect of additives, waste plastics and polypropylene on strength properties. The test was conducted at 0, 50, 75 and 100 kPa confinements. Analysis using Mohr-Coulomb failure theory shows that the stabilized SMA had highest cohesion and shear strength as compared to control mixture (SMA without additive), but almost similar angle of internal friction. SMA with waste plastics shows the highest cohesion and shear strength at 7% waste plastics. The strain at failure and tangent modulus increases with increasing confinement pressure, indicating their stress dependent behavior. The increase in tangent modulus indicates the increased elastic stiffness of stabilized SMA. The stress-strain curves show that the peak stress and the time of its occurrence is higher in waste plastics mixtures when compared to polypropylene mixtures. For stabilized mixtures, shape change of stress-strain curves is more gradual with increase in additive content and brittle type failure does not seem to occur as in control mixture.

Keywords: Triaxial test, Shear strength, Waste plastics, Polypropylene

INTRODUCTION

The Marshall test is a kind of unconfined compressive strength test. It is a good indication of the ideal binder content but fails to register the true shear strength of the mixture. The triaxial test, on the other hand, measures the mix stability in the form of shear strength of the mix. The strength of bituminous mixtures is due partly to the friction and interlocking of aggregates, which increases with increasing normal stress, and partly to cohesion or viscous resistance, which increases with increasing shear rate. According to (Crockford *et al*., 2002) the

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characterizations attainable with the proper conduct of this testing approach are generally considered to be more closely associated with the true engineering properties than any other test. McLeod (1951) used ϕ and c from triaxial tests to evaluate the maximum vertical load a pavement can carry. Triaxial test can be applied to flexible pavement design. Triaxial tests can be used as best to simulate the stress, temperature and strain conditions occurring in the field. Yoder and Witezak (1975) also suggested that the test offers a good means of evaluating pavement design.

In the laboratory, confining stresses are applied to simulate stress due to the surrounding material in a pavement structure. This confinement increases with increasing depth in the pavement. Thus, varying the confining pressure in a laboratory test simulates the material at different depths in the pavement. The deviator stress in the laboratory represents applied wheel loads in the field that are transmitted through the bituminous layers to the underlying unbound layers. Increasing the deviator stresses in the laboratory simulates increasing the applied load magnitude in the field.

Triaxial strength testing provides information concerning mixture cohesion and internal friction both of which should contribute to mixture rut resistance (Christensen *et al.*, 2000). Tangent modulus, an indication of the elastic stiffness modulus (Ebels and Jenkins, 2007) and stress and strain at failure can be obtained from the stress-strain diagram. Since bituminous mixtures have little or no tensile strength, shearing resistance of the mix is used to develop a load-distributing quality that greatly reduces the stresses transmitted to the underlying layers. The objective of the present study is to study the effect of waste plastics on the shear strength characteristics of Stone Matrix Asphalt mixtures and to compare the results with that of the expensive polymer additive polypropylene.

MATERIALS AND METHODS

The specimen size of 100 mm in diameter and 150 mm in height (Pellinen *et al.*, 2004) is used for the test. A test temperature of 60°□C is used in this study, which is an acceptable temperature level by many researchers. (Smith, 1951; Low *et al.,* 1995). Static truck loads represent the severest condition imposed on a bituminous pavement. Such loading can result in the accumulation of significant pavement deformation. Endersby (1951) found that in the triaxial test, the cohesion increases with increasing loading speed. Goetz and Chen (1957) reported that the angle of internal friction was not affected by the rate of strain, but the cohesion increases steadily as the rate of strain increases. A loading speed of 50.8 mm/min is selected for this study (Pellinen *et al.*, 2004), which is same as the rate of loading given for Marshall test.

The bitumen content for all the SMA mixtures were kept as 6.42% which is the optimum bitumen content for the control SMA mixture (without any additive). Samples are compacted to get a cylindrical sample of 100 mm diameter and 150 mm height. The specimen is encased in a rubber membrane to allow for confinement pressure to be applied all around the specimen. Water is used as the medium. Axial load is applied through a platen on the end of the cylindrical specimen, so as to get an unconsolidated undrained test condition. Test specimens are loaded beyond the peak load to understand the post peak behavior. Four different confinement pressures of 0, 50, 75 and 100 kPa are used in the testing (Bueno *et al.,* 2003, Ebels, 2008). For each confining pressure, three samples are tested and the average value is taken.

RESULTS AND DISCUSSION

Analysis using Mohr-Coulomb Failure Theory

Stone Matrix Asphalt (SMA) mixtures with WP and PP additives are investigated using triaxial shear strength testing. The cohesion and friction angle are obtained using the Mohr-Coulomb failure theory. The triaxial test results are tabulated in Table 1. The table shows the measured deviator stress (σ_d) obtained at each confinement level (σ_3). Figures 1 to 3 shows the plots of the Mohr-Coulomb failure envelope represented by the cohesion c and angle of internal friction ϕ for the control mixture and stabilized mixtures (3 samples for each confinement). Cohesion and friction are estimated using test results from different confinement levels to obtain at least three points in the failure line.

Cohesion

The computed cohesion values for each additive for different percentages are shown in Figure 4. Analysis of test data shows that the presence of additives has shown significant effect on cohesion, which increases approximately from 110 kPa in control mixture to and to about 145 kPa in SMA mixtures with waste plastics. All the SMA mixtures give the highest cohesion at 7% for waste plastics and

Table 1: Triaxial Shear Strength Test Results

Type of Additive	Confinement σ_3 (kPa)	Deviator Stress σ_d (kPa)	C (kPa)/ϕ(Deg.)
No additive	0	418.57	109.06/35
	50	553.45	
	75	613.06	
	100	681.88	
Waste plastics	0	570.26	145.55/35.6
	50	707.66	
	75	776.03	
	100	845.78	
Polypropylene	0	553.25	139.52/35.6
	50	691.19	
	75	752.12	
	100	830.98	

Figure 1: Mohr's Circle for Control Mixture

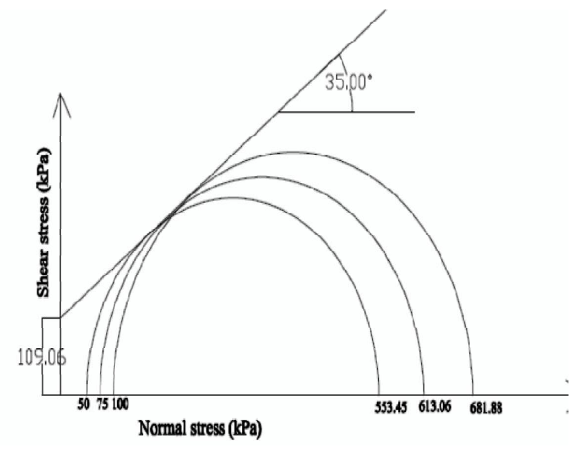


Figure 2: Mohr's Circle for WP Stabilized SMA

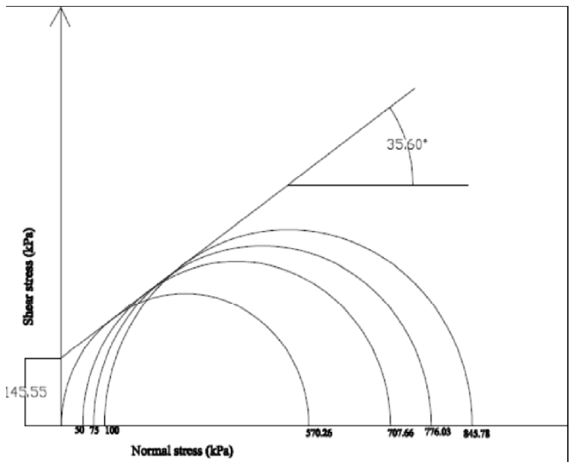
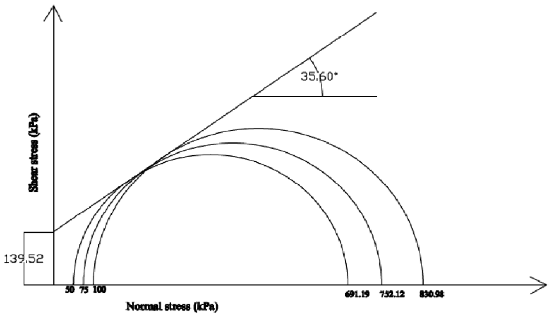
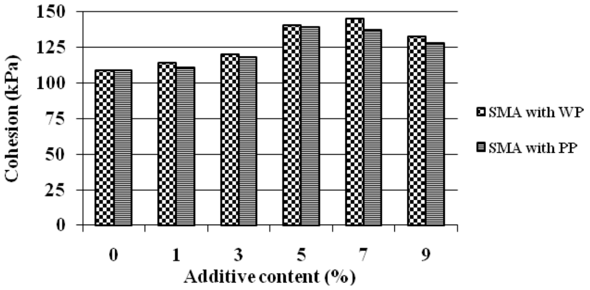


Figure 3: Mohr's Circle for Polypropylene Stabilized SMA



at 5% for polypropylene. The cohesion values are found to be decreasing when additive contents are increased beyond this percentage. Figure 4 shows that Waste plastics stabilized SMA mixtures show slightly higher cohesion value than the Polypropylene stabilized mixtures. When compared to the control mixture the percentage increase in cohesion value is about 33% and 28%, respectively for SMA mixture stabilized with WP and PP at 7% and 5% of additives. The larger the cohesion value, the higher the mix resistance to shearing stresses. This shows that all the stabilized mixtures have greater resistance to shearing stresses than the control mixtures.

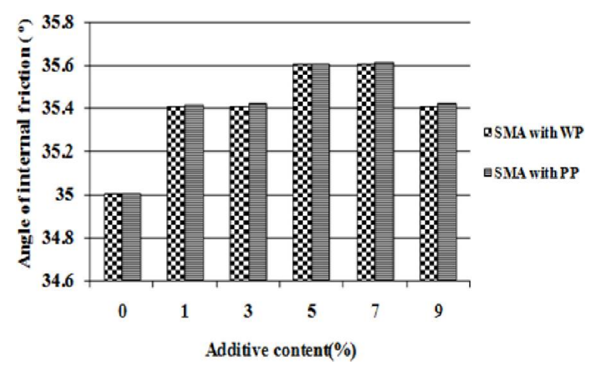
Figure 4: Variation of Cohesion with Different WP and PP Contents



Angle of Internal Friction

The variations of angle of internal friction of SMA mix with different percentages of additives are given in Figure 5. It can be observed that the presence of additives in SMA mix will not result in considerable variation in the angle of internal friction of mix as compared to the control mixture. The value of ϕ is 35.6° or WP and PP stabilized mixtures while 35° for the control mixture. The angle of internal friction value is an aggregate property, mostly dependent on aggregate properties

Figure 5: Variation of Angle of Internal Friction with Different WP and PP Contents



such as grading and angularity of particles. Therefore no significant variation is expected since all mixtures have the same aggregate gradations.

A slight increase in angle of internal friction is occurred for the stabilized mixtures. This slight increase in ϕ may be due to the influence of cohesion. The cohesion and friction angle are not entirely independent of each other since there is some sort of balancing effect as a result of the stabilization of the mixture (Jenkins, 2000).

The parameters c and ϕ are the strength indicators of mixtures. The larger the c value, the larger the mix resistance to shearing stresses. In addition, the larger the ϕ value, the larger the capacity of the bituminous mixture to develop strength from the applied loads, and hence, the smaller the potential for permanent deformation. The cohesion values of all mixes with additives are higher than that of the control mixture, showing their higher resistance to shearing stresses.

Shear Strength

The cohesion and angle of internal friction cannot be evaluated and compared in isolation. When comparing the performance of several mixes, the maximum shear stress that the mixture can withstand is of importance. This is dependent both on cohesion and angle of internal friction.

Shear strength is computed at 300 kPa normal stresses which represents hypothetical pavement stress at the edge of the tyre at 75-mm deep in the pavement (Pellinen *et al.*, 2004). The test results are shown in Table 2. It can be seen that, with additives, SMA mixture retained higher shear strength. This suggests that the stabilized mixture is less prone to rutting by shear and densification compared to the control mixture. In order to densify mixtures by traffic the rearrangement of aggregate structure must take place by coupled action of volumetric and shear straining. Based on these findings the stabilized mixtures seem to be less prone to dilatation and shear compared to the control mixture. WP stabilized SMA mixture shows the maximum shear strength of about 364 kPa. The percentage increase in strength is about 14% with respect to the control mixture, showing their much greater resistance to shearing stresses. The results indicate that the shear resistance is rising mostly from cohesion since the variation of ϕ is observed to be marginal.

Table 2: Shear Strength of Various SMA Mixtures

Type of mixture	Shear strength (kPa)
Control mixture	319.12
SMA with WP	363.51
SMA with PP	355.63

The test results showed that stabilized mixes are stronger than the control mix. The presence of additives makes the mixes more flexible. Surface layer built with this stabilized SMA may not become rigid under traffic loading and, therefore, less susceptible to cracking.

Stress-Strain Curves for SMA Mixture

Figure 6 (a) and (b) represents the variation of deviator stress with strain for all stabilized mixtures at 100 kPa confinement level for different percentages of additives. The plots represent before and after peak stress development during the test. The peak stress was obtained by examining the graphs. For the stabilized mixture, it is observed that the peak stress developed and the time of its occurrence are higher when compared to those of the control mixture, a behavior that was attributed to the influence of additives in the mix. The additives provide this additional reinforcement to bituminous mix in resisting permanent deformation and retard the occurrence of shear failure. In all tests, the stabilized mixtures showed higher maximum stress at failure than the control mixture. SMA mixture with additives showed better resistance to shear deformation as shown by the triaxial shear strength test results. Notably, post peak failure for the additive reinforced bituminous mixtures showed gradual drop in strength, an effect that was attributed to the influence of the additives in the mix.

Figure 6a: Variation of Deviator Stress With Strain of SMA With Different Percentages of Waste Plastics

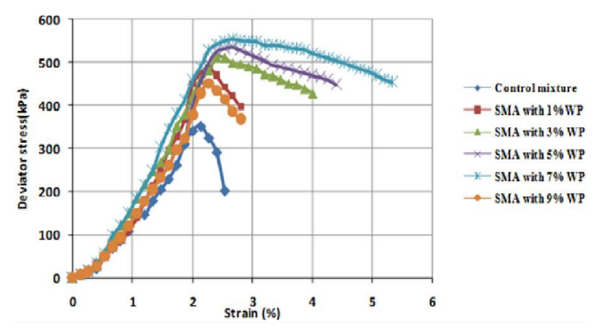
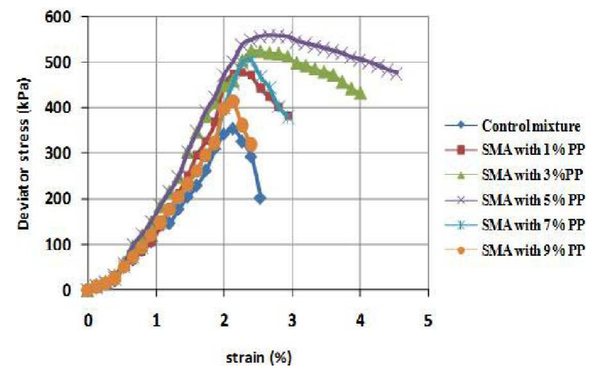


Figure 6b: Variation of Deviator Stress With Strain at Different Percentages of Polypropylene



By examining the stress-strain curves for the SMA mixtures, it can be inferred that in stabilized mixtures, the shape change of the stress-strain curves is more gradual with increase in additive content and brittle type failure does not seem to occur. Also, the failure strains are slightly higher. The following phenomena were observed during testing based on visual observations, inspection of stress-strain curves and failed specimens for SMA mixtures. For SMA mixtures, at around 0.5% axial strain aggregates started to slip initiating a structural transformation. This process continued until aggregate particle interlock was overcome and dilatation (volume increase) took place in the specimen.

Strain and Stress at Failure

Strain and stress at failure are parameters that could provide some additional insight into the material characterization. These values for stabilized SMA at various additive contents at 100 kPa confinement pressures are given in Table 3. The stress and strain values at failure increases due to the inclusion of additives up to 0.3% fibre content, 5% PP content and 7% WP content in SMA and after that it is found to be decreasing.

The variation of maximum failure strain and the corresponding stress for different confinement pressures for all SMA mixtures are summarized in Figures 7 and 8.

Figure 7: Maximum Strain at Failure at Different Confinement Pressures

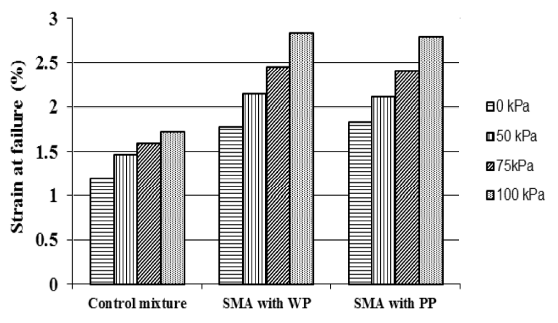


Figure 8: Maximum Stress at Failure at Different Confinement Pressures

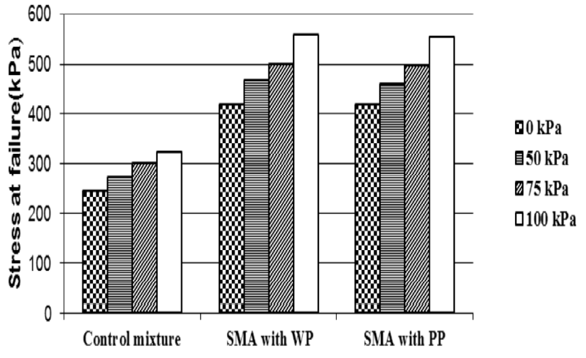


Figure 9: Tangent Modulus at Different Confinement Pressures

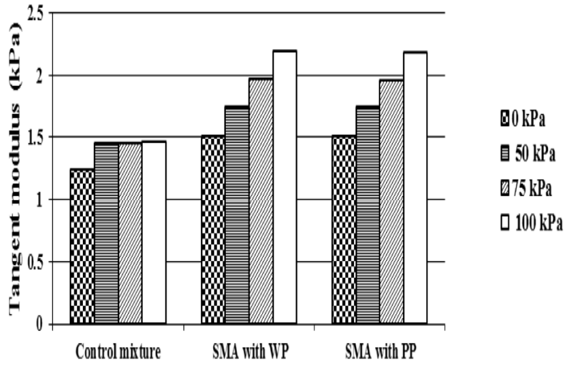


Table 3: Strain and Stress at Failure for Stabilized SMA at Different Percentages of WP and PP (100 kPa Confinement Pressure)

Additive (%)	Waste plastics		Polypropylene	
	Strain at failure (%)	Stress at failure(kPa)	Strain at failure (%)	Stress at failure (kPa)
0	2.13	352.5	2.13	352.5
1	2.27	486.45	2.27	476.45
3	2.4	512.45	2.4	524.68
5	2.53	542.58	**2.67**	**554.42**
7	**2.93**	**559.46**	2.4	504.587
9	2.27	454.85	2.13	414.568

Tangent Modulus

Another material property that may be derived from the triaxial test is the tangent modulus. The maximum tangent modulus of all mixtures including the control mixture at different confinement pressures are summarized in Figure 9. All stabilized mixes show high tangent modulus than the control mixture. As the confining pressure increases, the tangent modulus value increases. The tangent modulus exhibited a stress dependent behavior. It can be seen that the tangent modulus generally varies between 1.2 kPa for control mixture to 2.3 kPa for SMA with 0.3% coir fibre. As the tangent modulus is obtained from the linear part of the stress- strain diagram, it should provide an indication of the elastic stiffness of the material. It is evident that the presence of fibre in the mix enhances the elastic stiffness of the SMA mixture.

CONCLUSION

Analysis using Mohr-Coulomb failure theory shows that the SMA stabilized mixtures had highest cohesion and shear strength as compared to the control mixture. But all the mixes had almost similar angle of internal friction value, which is mostly dependent on aggregate properties such as grading and angularity of particles. Therefore no significant variations, since all mixtures have the same aggregate gradations.

For stabilized SMA mixtures, the highest cohesion and shear strength results are at 7% WP and 5% PP content respectively. Analysis however suggests that the high additive content beyond this percentage prevents the mixtures to develop aggregate interlock and therefore less cohesion and shear resistance.

By examining the stress-strain curves for the SMA mixture, it can be inferred that in the stabilized mixture, the peak stress developed and the time of its occurrence is higher when compared to those of the control mixture. For stabilized mixtures, the shape change of the stress-strain curves is more gradual with increase in additive content and brittle type failure does not seem to occur as in the case of control mixture.

There is a trend that the strain at failure and tangent modulus increases with increasing confinement pressure, indicating their stress dependent behavior. The increase in tangent modulus value of SMA mixture in presence of additives indicates the increased elastic stiffness of the stabilized SMA.

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