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Shear Strength Characteristics of Coir Fibre Stabilised Stone Matrix Asphalt Mixtures

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Abstract

The triaxial test measures the mix stability in the form of shear strength and gave better information for the prediction of field performance. The stresses acting on the laboratory specimen during the test simulate the state of stresses existing in the pavement. The Stone Matrix Asphalt mixtures (SMA)were investigated using triaxial shear strength testing at 50.8 mm/min ram rate loading at 60°C to investigate the effect of additive, coir fibre on the strength properties by varying the percentages of fibre. SMA without fibre is taken as the control mixture. The test was conducted at 0, 50, 75 and 100kPa confinements. The Mohr-Coulomb failure theory was used to analyze the test data and the analysis shows that the SMA stabilized mixtures had highest cohesion and shear strength as compared to the control mixture, but almost similar angle of internal friction value. The higher values of cohesion and shear strength can be associated to a fibre content of 0.3% and the percentage increase in cohesion is about 53% with respect to the control mixture. This shows that the mixture has greater resistance to shearing stresses than the control mixture. There is a trend that the strain at failure increases with increasing confinement pressure, indicating their stress dependent behaviour. The stress-strain curves indicate that the peak stress developed and the time of its occurrence is higher in stabilized mixtures when compared to those of the control mixture. For stabilized mixtures, it is observed that the shape change of the stress-strain curves is more gradual with increase in fibre content and brittle type failure does not seem to occur as in the case of control mixture.

Keywords: *Triaxial test, Stone Matrix Asphalt, Shear strength*

1.0 Introduction

Stone matrix asphalt (SMA) mixture is an impervious wearing surface which provides rut resistant and durable pavement surface layer[1]. The Indian Roads Congress has adopted a tentative SMA specification [2]. One test road was constructed in Delhi in October 2006, using SMA as a surfacing course. By considering the advantage of the proven field performance of this test track and in other regions of developed countries with climatic conditions reasonably close to that of India, SMA can be considered as the right choice for long lasting pavements. 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.

Triaxial strength testing is a simple performance test for rut resistance. It is relatively quick, simple and inexpensive, and its simplicity should ensure good repeatability. This test provides information concerning mixture cohesion and internal friction both of which should contribute to mixture rut resistance [3]. Tangent modulus, an indication of the elastic stiffness modulus [4] and stress and strain at failure can be obtained from the stress-strain diagram. The main objective of this paper is to propose a durable surface course with stone matrix asphalt by exploring the utilization of natural fiber coir as additive and to assess the influence of the fibre on the shear characteristics of SMA mixtures.

2.0 Literature Review

Stone Matrix Asphalt is a hot mix asphalt, developed in Germany during the mid- 1960's. It is a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler, with relatively little sand sized particles. It has low air voids with high levels of macro texture when laid resulting in waterproofing with good surface drainage [5]. SMA consists of discrete single sized aggregates glued together to support themselves by a binder rich mastic. The mastic is comprised of bitumen, fines, mineral filler and a stabilising agent. Additives such as fibres or polymers are used as a stabilizer to secure the mastic within the overall structure. They stiffen the resulting mastic and prevent the draining off binder during storage, transportation and placing of SMA. They play the role of minimizing the binder drain down, increasing the amount of binder used in the mix and improving the mix durability. Currently imported synthetic fibres /expensive polymers are used as additives in SMA. Glass fibre, rock wool, polyester, and even natural wool, have all been found to be suitable but cellulose fibre is generally the most cost-effective one. Behbahani et al. [6] found that the variation of fibre type and content can lead to considerable changes in the rutting performance of Stone Mastic Asphalt mixtures. Natural fibre, coir which is abundantly available in Kerala is used for the study as an alternative to synthetic fibres and polymer additives.

Fundamentally, fibre improves the different properties of the resulting mix. It changes the viscoelasticity of the modified bitumen[7], increases dynamic modulus[8], moisture susceptibility [9], creep compliance, rutting resistance[10] and freeze– thaw resistance[11], while reducing the reflective cracking of bituminous mixtures and pavements [11,12,13]. Goel and Das [14] reported that fibre-reinforced materials develop good resistance to ageing, fatigue cracking, moisture damage, bleeding and reflection cracking. Aggregate interlock and particle friction are maximized and gives the structure its stability and strength [15].

3.0 Experimental Programme

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

3.1 Material characterization

Aggregate of sizes 20mm, 10mm and stone dust procured from a local quarry at Kochi, Kerala is used in the present investigation and the physical properties are given in Table 1. Ordinary Portland cement from a local market which makes a better bond with aggregate, bitumen and additive is used as the filler material and the physical properties are shown in Table 2. Bitumen of 60/70 penetration grade obtained from Kochi Refineries Limited, Kochi, is used in the preparation of samples and the physical properties are given in Table 3. Natural fibre, coir, locally procured from Alappuzha, Kerala at different percentages by weight of mixture are used as the stabilizing additive. The photograph of this fibre is shown in Figure. 1 and their properties are given in Table 4.

Table 1: Physical properties of aggregates

Property	Result	Method of Test
Aggregate impact value (%)	16	IS:2386 (IV)
Los Angeles Abrasion Value	27	IS:2386 (IV)
Combined Flakiness and Elongation Index (%)	18	IS:2386 (I)
Stripping Value	Traces	IS 6241:1971 (R2003)
Water Absorption (%)	Nil	IS:2386 (III)
Specific gravity	2.65	IS:2386 (III)

Table 2: Physical properties of cement

Physical property	Result
Specific gravity	3.12
% passing 0.075 mm sieve (ASTM C117)	96

Table 3: Physical properties of bitumen

Property	Result	Test procedure
Specific Gravity @ 27˚C	1	IS:1202 - 1978
Softening Point (˚C) (R&B Method)	50	IS:1205 - 1978
Penetration @ 25˚C,0.1 mm 100g, 5 sec	64	IS:1203 - 1978
Ductility @ 27˚C (cm)	72	IS:1208 - 1978
Flash Point (˚C) Fire Point (˚C)	240 270	IS:1209 – 1978
Viscosity at 60 ˚C (Poise)	1200	IS:1206 – 1978
Elastic recovery @ 15˚C (%)	11	IRC: SP:53 – 2002

Figure 1: Coir fibre

Table 4: Physical properties of fibres

Property	**Coir fibre**
Diameter (μm)	100 - 450
Density (g/cm^3)	1.45
Cellulose content (%)	43
Lignin content (%)	45
Elastic modulus(GN/m^2)	4-6
Tenacity (MN/m^2)	131 - 175
Elongation at break (%)	15 - 40

3.2 Gradation of aggregates

The sieve analysis, blending and the specified limits of the SMA mixture given in Table 5 as per NCHRP, TRB[16].

3.3 Mix design

For the design mix gradation, four specimens are prepared for each bitumen content within the range of 5.5 – 7.5% at increments of 0.5 percent, in accordance with ASTM D 1559 using 50 blows/face compaction standards. All bitumen content is in percentage by weight of the total mix. As soon as the freshly compacted specimens have cooled to room temperature, the bulk specific gravity of each test specimen is determined in accordance with ASTM D 2726[17]. The stability and flow value of each test specimen is determined in accordance with ASTM D 1559. After the completion of the stability and flow test, specific gravity and voids analysis is carried out to determine the percentage air voids in mineral aggregate(VMA) and the percentage air voids in the compacted mix(VA) and voids filled with bitumen(VFB). Values which are obviously erratic is discarded before averaging. Where two or more specimens in any group of four are so rejected, four more specimens are prepared and tested.

The average values of bulk specific gravity, stability, flow, VA, VMA and VFB obtained above are plotted separately against the bitumen content and a smooth curve drawn through the plotted values. Average of the binder content corresponding to VMA of 17 % and an air void of 4% are considered as the optimum binder content (OBC) [18]. Stability and Flow values at the optimum bitumen content are then found from the plotted smooth curves The OBC for the SMA mixture is determined and is 6.42 % (by wt. of total mix). The SMA mixture without additives is considered as the control mixture for the triaxial test.

3.4 Triaxial Test

The specimen size of 100 mm in diameter and 150 mm in height [19] is used for the triaxial test. A test temperature of 60˚C is used in this study, which is an acceptable temperature level by many researchers. [20,21]. Static truck loads represent the severest condition imposed on a bituminous pavement. A loading speed of 50.8 mm/min is selected for this study, which is same as the rate of loading given for Marshall test.

The bitumen content for all the SMA mixtures are kept as 6.42% which is the OBC for the control SMA mixture (without fibre). Samples are prepared by varying the fibre content 0.1%, 0.2%, 0.3% and 0.4% by weight of mixture and 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 behaviour. Four different confinement pressures of 0, 50, 75 and 100 kPa are used in the testing [22,23]. For each confining pressure, three samples are tested and the average value is taken. The triaxial test results are tabulated in Table 6.

Table 5: Gradation of aggregates and their blends for SMA mixture

Sieve size (mm)	**Percentage passing**				**Adopted Grading A: B: C: D 50:30:11:9**	**Specified Grading NCHRP, TRB**
	20 mm (A)	**10 mm (B)**	**Stone dust (C)**	**Cement (D)**		
25.0	100	100	100	100	100	100
19.0	98	100	100	100	99	90 -100
12.5	20	100	100	100	60	50 - 74
9.50	4	58	100	100	39	25 - 60
4.75	0	6	100	100	22	20 - 28
2.36	0	0	92	100	19	16 - 24
1.18	0	0	77	100	17	13 - 21
0.6	0	0	64	100	16	12 - 18
0.3	0	0	45	100	14	12 - 15
0.075	0	0	6	96	9	8 - 10

4.0 Results and Discussions

Stone Matrix Asphalt (SMA) mixtures with coir fibre are investigated using triaxial shear strength testing.

4.1 Analysis using Mohr-Coulomb failure theory

The cohesion and friction angle are obtained using the Mohr-Coulomb failure theory. Figure 2 and Figure 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 coir fibre stabilized mixture (3samples 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. The variation of shear parameters at various fibre contents are given in Table 7.

4.2 Cohesion

Analysis of test results shows that the presence of additives has shown significant effect on cohesion, which increases from 106 kPa in control mixture to 167 kPa in SMA mixtures with coir fibre. Table 7 shows that SMA mixtures give the highest cohesion at 0.3%fibre content. The cohesion values are found to be decreasing when fibre contents increased beyond this percentage. 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. The percentage increase in cohesion is about 53% with respect to the control mixture.

4.3 Angle of internal friction

It is observed that the presence of additives in SMA mix did not result in considerable variation in the angle of internal friction as compared to the control mixture. The value of φ is 36˚for fibre-stabilized mixes, while 35˚ for the control mixture. The angle of internal friction value is an aggregate property, mostly dependent on aggregate properties 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 observed for the

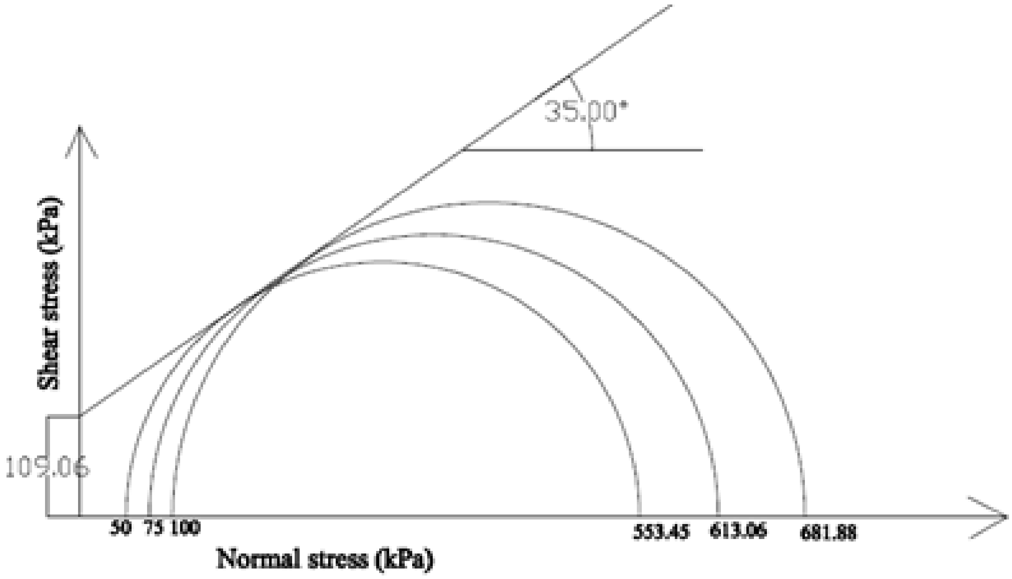

Figure 2: Mohr's circle for Control mixture

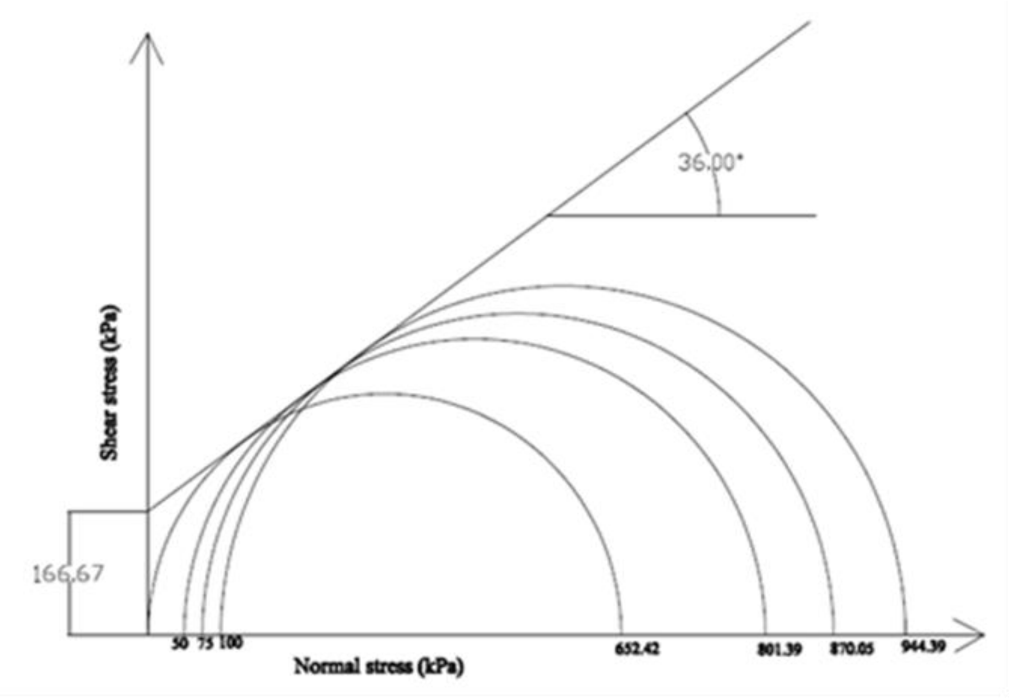

Figure 3: Mohr's circle for Coir fibre stabilized SMA

mixtures at a fibre content of 0.3% (Table 7) and the percentage increase is only about 3 % with respect to the control mixture. This slight increase in φ may be due to the influence of cohesion.

4.4 Shear strength

The cohesion and angle of internal friction cannot be evaluated and compared in isolation. When comparing the performance of 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 [19]. The test results are shown in Table 8.

It can be seen that, with fibres, 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. The percentage increase in strength is about 21% 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 6: Triaxial shear strength test results

Additive	Confinement σ_3 (kPa)	Deviator stress σ_d (kPa)	C (kPa)/ φ (Deg.)
Nil	0	418.57	109.06/35
	50	553.45	
	75	613.06	
	100	681.88	
Coir fibre	0	652.42	166.67/36
	50	801.39	
	75	870.05	
	100	944.39	

Table 7: Shear parameters at various fibre contents

Fibre content (%)	Cohesion (kPa)	Angle of internal friction (^{0})
0	109.06	35
0.1	132.87	35.4
0.2	151.62	35.6
0.3	166.7	36
0.4	132.09	35.5

Table 8: Shear strength of various SMA mixtures

Type of mixture	Shear strength (kPa)
Control mixture	319.12
SMA with coir	384.63

4.5 Stress-strain curves

Variation of deviator stress with strain for SMA mixture at 100kPa confinement level for different percentages of fibre are shown in Figure 4. 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 behaviour that was attributed to the influence of fibres in the mix. The additives provide this additional reinforcement to bituminous mix in resisting permanent deformation and retard the occurrence of shear failure. Notably, post peak failure for the fibre reinforced bituminous mixtures showed gradual drop in strength, an effect that was attributed to the influence of the fibres in the mix.

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 fibre content and brittle type failure does not seem to occur. Also, the failure strains are slightly higher.

4.5.1 Confinement effect

Table 9 shows the variation of strain at failure at different confinement pressures. Looking at the confinement pressure only, there is a trend that strain at failure increases with increasing confinement pressure. This indicate that strain at failure is a stress dependent behaviour. It can be seen that strain at failure ranges from 2.13% for the control mixture to 3.07 % for coir fibre stabilized SMA at the highest confinement pressure.

Figure 5 summarizes the measured axial failure strains for the coir fibre stabilized SMA mixture at 0.3% fibre content for different confinement levels. By examining stress-strain curves, it can be observed that the strain at failure increases with increasing confinement pressure rendering it a stress dependent parameter. Variation of deviator stress with strain for SMA mixture at 100kPa confinement level for different percentages of fibre are shown in Figure 5. 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 behaviour that was attributed to the influence of fibres in the mix. The additives provide this additional reinforcement to bituminous mix in resisting permanent deformation and retard the occurrence of shear failure. Notably, post peak failure for the fibre reinforced bituminous mixtures showed gradual drop in strength, an effect that was attributed to the influence of the fibres in the mix.

Table 9: Strain at failure (%)at different confinement pressures

SMA Mixture	**Strain at failure(%)**			
	0 kPa	**50 kPa**	**75kPa**	**100kPa**
Without fibre	1.2	1.47	1.6	1.73
with fibre	2.13	2.4	2.67	3.07

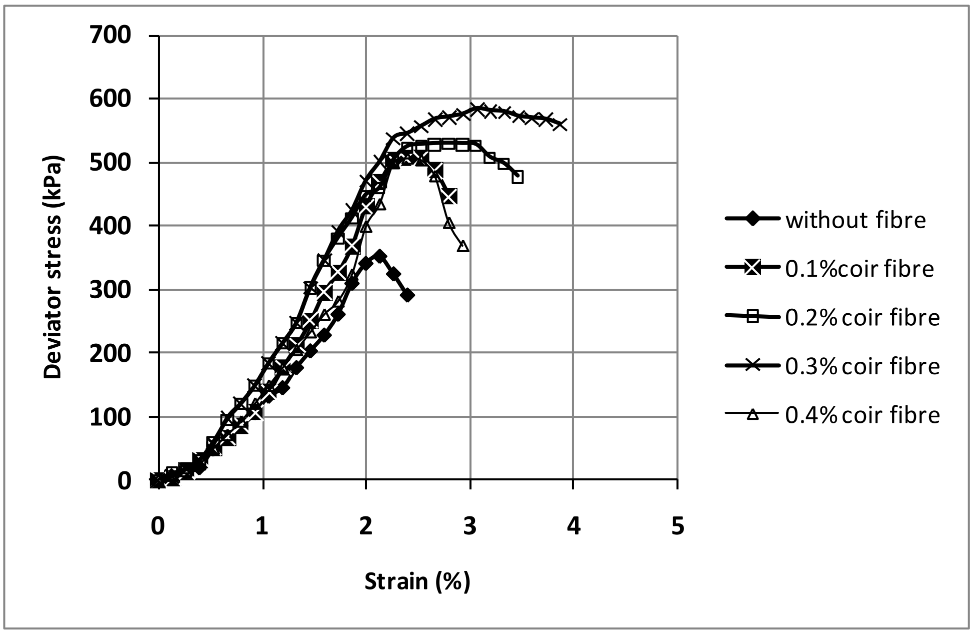

Figure 4: Variation of deviator stress with strain of SMA with different percentages of coir fibre.

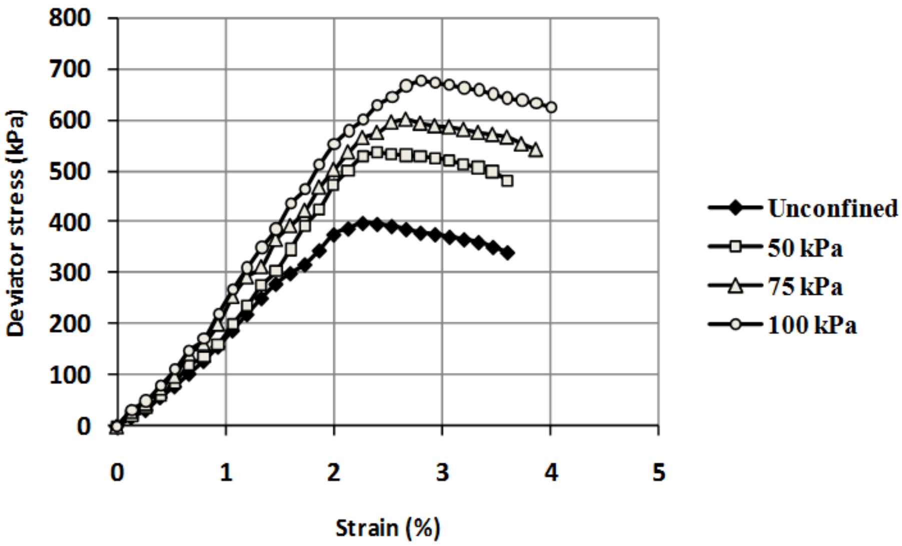

Figure 5: Stress strain behaviour at various confinement pressures for Coir fibre stabilized SMA.

5.0 Conclusions

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 are expected since all mixtures have the same aggregate gradations. The higher values of cohesion and shear strength can be associated to the fibre content of 0.3%. Analysis shows that the high fibre content beyond this percentage prevents the mixtures to develop aggregate interlock and therefore less cohesion and shear resistance. When compared with the control mixtures, SMA mixtures with fibre has 1.5 times higher cohesion. Looking at the confinement pressure only, there is a trend that strain at failure increases with increasing confinement pressure which indicate that strain at failure is a stress dependent behaviour. The strain at failure ranges from 2.13% for the control mixture to 3.07 % for coir fibre stabilized SMA at the highest confinement pressure. By examining the stress-strain curves, 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.

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