SHEAR STRENGTH CHARACTERISTICS AND STATIC RESPONSE OF SAND-TIRE CRUMB MIXTURES FOR SEISMIC ISOLATION

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Abstract

The objective of this study is to investigate the shear strength characteristics, energy absorption capacity and brittleness index of sand-tire crumb mixtures using simple direct shear test and Unconsolidated Undrained (UU) triaxial test for the effective use of waste tire crumbs for seismic isolation of building. Tire crumbs were prepared with special machinery where scrap tires were crushed into pieces and powders after removal of steel belting. The processed tire crumbs obtained from local industry were sieved into four size groups, i.e. 8 mm - 5.6 mm, 5.6 mm - 4.75 mm, 4.75 mm - 2 mm, and 2 mm - 1 mm and relatively uniform sand has been selected to generate sand-tire crumb mixtures (STCM). Grouped tire crumbs are mixed with sand to generate STCM samples having 0%, 10%, 15%, 20%, 25%, and 30% tire crumbs by volume. Direct shear and UU triaxial compression tests have been carried out on STCM samples for different normal and confining pressure with constant density of 1.54 g/cc. Stress-strain curves obtained from UU test for different confine pressure have been used to estimate energy absorption capacity by measuring area of stress-strain curve up to strain level of 20% for different size and percentage of tire crumbs. The experimental results show that the parameters controlling shear strength, energy absorption and stiffness are tire crumb size, percentage of crumbs, normal stress and confining pressure. Peak strength was significantly increased by adding rubber with sand. It is found that peak strength, energy absorption and stiffness increases with increasing percentage of tire crumbs up to 25%. Among tests of different tire crumb sizes, 5.60 mm gives maximum efficiency than other crumb sizes.

Keywords: Brittleness index, Energy absorption, Sand-tire crumb mixtures, Shear strength

1. Introduction

1.1 General

Over last few years, recycling of waste materials as construction materials has been considered important to solve economical and technical problems for sustainable environment. In ground improvement techniques, waste materials are also used to improve geotechnical properties. Major waste materials often used in soil mechanics are waste tyres, rubbers, and plastic materials from pet bottles. Materials such as tire crumbs were widely used as light weight materials for backfill in embankment construction due to shortage of natural resources and increasing waste disposal cost (Edincliler et al., 2010). Processed old vehicle tires are being used as lightweight material for backfill in embankment construction due to growing interest in utilizing waste materials in civil engineering applications. Reuse of scrap/waste tires would not only provide a way of disposing them, but also helps to solve economical and technical problems for sustainable environment. One promising approach in waste tyre utilization is vibration reduction and seismic isolation of building taking into account of the high damping behaviour in rubber (Tsang, 2008; Tsang et al., 2012). However, systematic studies of the static and dynamic properties of sand tire crumb mixtures are limited. The objective of the study is to assess the shear strength characteristics and energy absorption capacity of sand-tire crumb mixtures (STCM) considering different size of tire crumbs and percentage of mixing. Direct shear and Unconsolidated Undrained (UU) triaxial tests have been carried out on STCM samples for different normal and confining pressure. Peak strength, ultimate strength, ductility and toughness (energy absorption capacity) of STCM are estimated for four ranges of tire crumbs size of 8 mm - 5.6 mm, 5.6 mm - 4.75 mm, 4.75 mm - 2 mm, and 2 mm - 1 mm and tire crumbs amount of 0%, 10%, 15%, 20%, 25%, and 30% of total volume of the sample.

1.2 Background

Many researchers have carried out laboratory studies to estimate the fundamental engineering properties of shear strength, permeability, compressibility and compaction characteristics rubber soil mixtures for application of light weight backfill material for embankments and retaining structures, foundation beds and others (Mahmoud, 2004; Foose et al., 1996; Masad et al., 1996; Wei et al., 1997; Edil and Bosscher, 1994; Lee et al., 1999; Young et al., 2003; Tatlisoz et al., 2010; Edincliler et al., 2004; Maher and Gray, 1990). In addition, Lee and Roh, (2007), used tire chip mixtures as backfill to improve the characteristics of compacted soils and to reduce dynamic earth pressure for culvert walls induced by construction loading. Edincliler et al., (2004 and 2010), reviewed the previous studies that reported with the state-of-the-art research on soil reinforced with rubber. Their review shows that inclusion of rubber definitely provides increase in material strength and deformation behaviour. Sand mixed with randomly distributed rubber is expected to behave as reinforced soil to improve geotechnical properties. Due to its high damping behaviour of rubber, when mixed with sand can be used for vibration reduction. These characteristics of sand-rubber mix help recycling of waste tires on a large scale in geotechnical applications. Sand-tire composite behaviour is governed by the content of rubber and mechanical properties of sand and rubber. The several studies were carried out to understand the influence of rubber tire in the mechanical behaviour of STCM. However, very limited study was carried out to understand the energy absorption capacity of STCM using static tests. In present study, energy absorption capacities of STCM for different size of tyre crumbs and percentage of mix are evaluated based on the stress-strain curves obtained from UU test.

2. Materials used

2.1 Sand

The soil particles used in present study were granulated passing through 4.75 mm sieve. The grain size of sand is between 0.075 mm and 4.75 mm, and its distribution curve is shown in Figure 1. The specific gravity of sand is 2.65, with uniformity and curvature coefficients of 3.50 and 1.14 respectively. The maximum and minimum densities of this sand were 1.434 and 1.786 g/cc. The sand is classified as uniformly graded sand according to unified soil classification system ASTM-D2487 (2003).

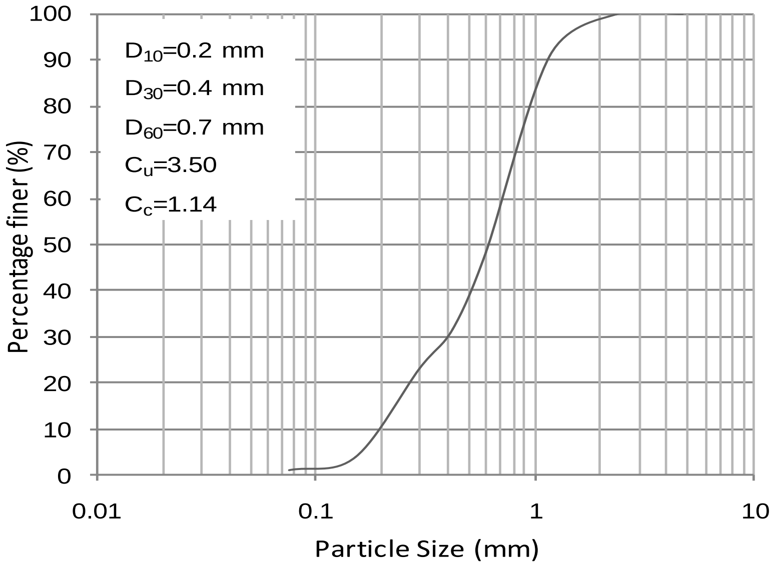


Figure1: Particle size distribution curve

2.2 Tire crumbs

Tire crumbs were prepared with special machinery where scrap tires were crushed into pieces and powdered after removing steel belting. The processed tire crumbs obtained from local industry were sieved into four size groups, i.e. 8 mm - 5.6 mm, 5.6 mm - 4.75 mm, 4.75 mm - 2 mm, and 2 mm - 1 mm. The specific gravity and water absorption value of the tire crumbs was determined as per ASTM-D854 (2010) and C128 (2007) and found to be 1.14 and 3.85.

3. Specimen preparation and testing procedures

In this study, STCM samples were prepared by considering constant density of 1.54 g/cc. STCM mix has been generated for 10%, 15%, 20%, 25% and 30% rubber by volume. The amount of sand and tire crumb required for each percentage composition was estimated for sample size. Tire crumb specimens were prepared by hand mixing with dry sand. The sand-tire crumbs were transferred into mould in layers with uniform mix, such that segregation would not occur during sample preparation.

Small direct shear test apparatus with rectangular mold having a size of 60 mm x 60 mm, and thickness of 30 mm was used to perform shear test on STCM samples. Tests were carried out based on the procedure described in ASTM-D5321 (2008) for three normal stresses of 50, 100 and 150 kN/m^2. Tests were carried out for samples containing of pure sand, and four mixtures of sand and tire crumbs, i.e., 10%, 15%, 20%, 25% and 30% rubber by volume. The samples were then tested at a constant rate of strain of 0.25 mm/min.

The static triaxial test was carried out for sample size of 38 mm in diameter by 76 mm in height for effective confining pressures of 20, 60 and 100 kN/m^2. The samples were tested out based on procedure described in ASTM-D2850 (2007). The prepared STCM samples were poured into vacuum split mould in 4 to 5 layers to achieve uniform mixing, and were slightly compacted for higher percentage of rubber. Triaxial tests were carried out on STCM of same composition at a constant rate of strain of 1.25mm/min.

4. Test results and discussions

Shear strength characteristics of the composite materials were examined with respect to the size of tire crumbs, the percentage of tire crumbs and the applied normal stress on the samples in the direct shear test. Similarly, the effects on energy absorption and deformation characteristics of the composite materials were examined through UU triaxial test. In this section, the results of the laboratory tests are presented with discussion highlighting the effects of various parameters.

4.1 Direct shear test

Stress-strain plot from direct shear test for 5.6 mm - 4.75 mm size tire crumbs are shown in Figure 2 for all five percentages (of rubber) and normal stress of 100 kN/m^2. It can be noticed from Figure 2 that for all STCM (except 30%), a clear peak shear stress is observed. The shear stress of STCM of 30% still tends to increase slightly beyond strain value of 12%, but the values are lower than other STCM.

Variation of volumetric strain against shear strain of STCM with 5.6 mm crumb size and different percentage of rubber at normal stress of $100kN/m^2$ is shown in Figure 3. It can be observed from Figure 3 that for a given normal stress, STCM samples were initially compressed and dilate upon shearing. This behaviour increases with increasing rubber content for all sizes of tire crumb.

Figure 4 shows shear stress versus normal stress for STCM for 5.6 mm - 4.75 mm size of tire crumbs and five percentage of rubber. For different applied normal stresses, shear resistance of STCM were higher than that of pure sand, but the increasing trend maintains up to 25% of rubber, beyond which the shear resistance decreases. Also it can be observed in Figure 4 that there is significant increase in shear resistance of STCM's except few combinations. The Mohr-Coulomb envelopes obtained from all samples of different sizes are almost linear. These envelopes match with the results in the literatures (Tatlisoz et al., 1997 and Ghazavi, 2004). The linear behaviour is due to small grain sizes of rubber particles which were distributed randomly in the mixture to form a continuum material with granular behaviour (Ghazavi, 2004).

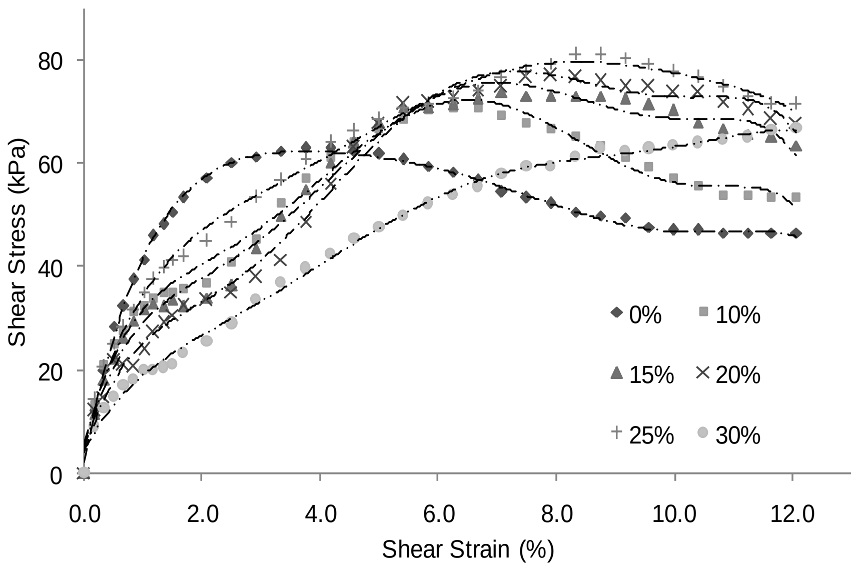


Figure 2: Typical plot of variation of shear stress with shear strain for 5.6 mm crumb size with different percentage of rubber mix at normal stress of 100 kN/m^2

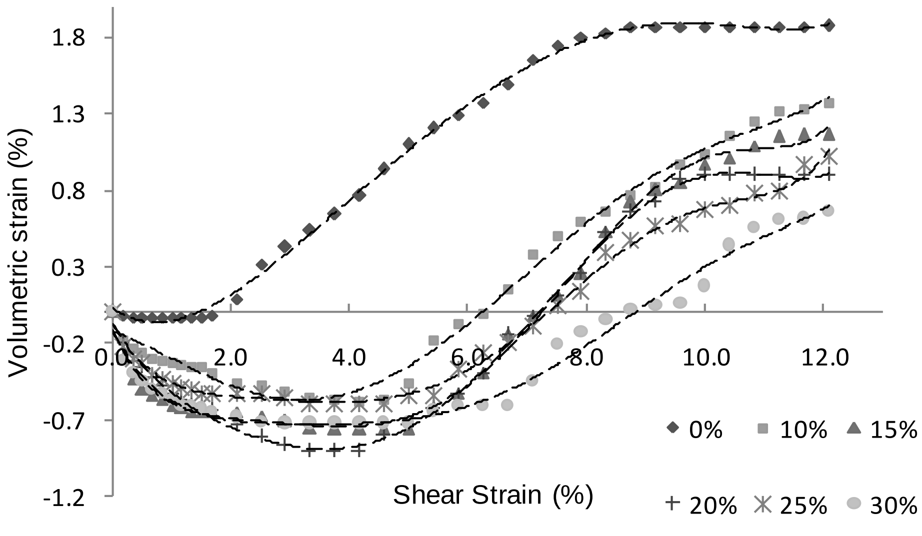


Figure 3: Typical plot of variation of volumetric strain with shear strain for 5.6 mm crumb size with different percentage of rubber mix at normal stress of 100 kN/m^2

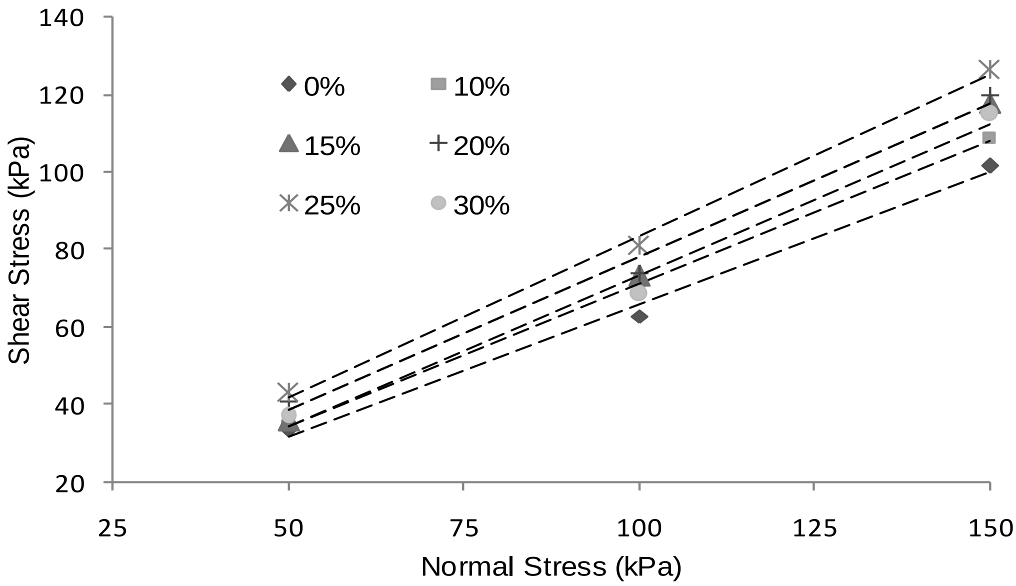


Figure 4: Typical plot of variation of shear stress with normal stress for 5.6 mm crumb size with different percentage of rubber mix

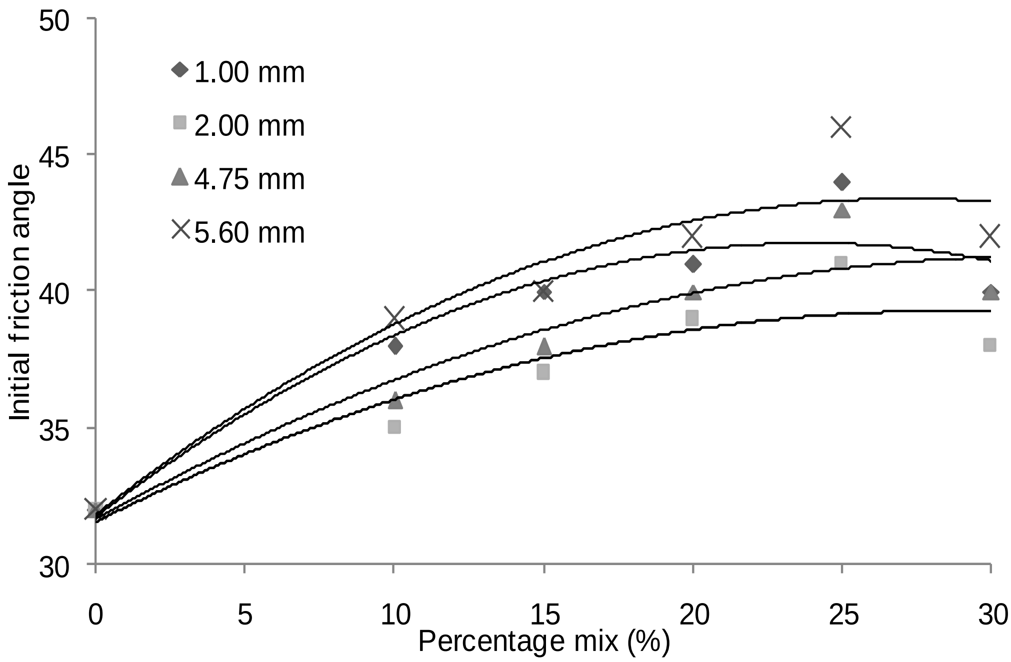
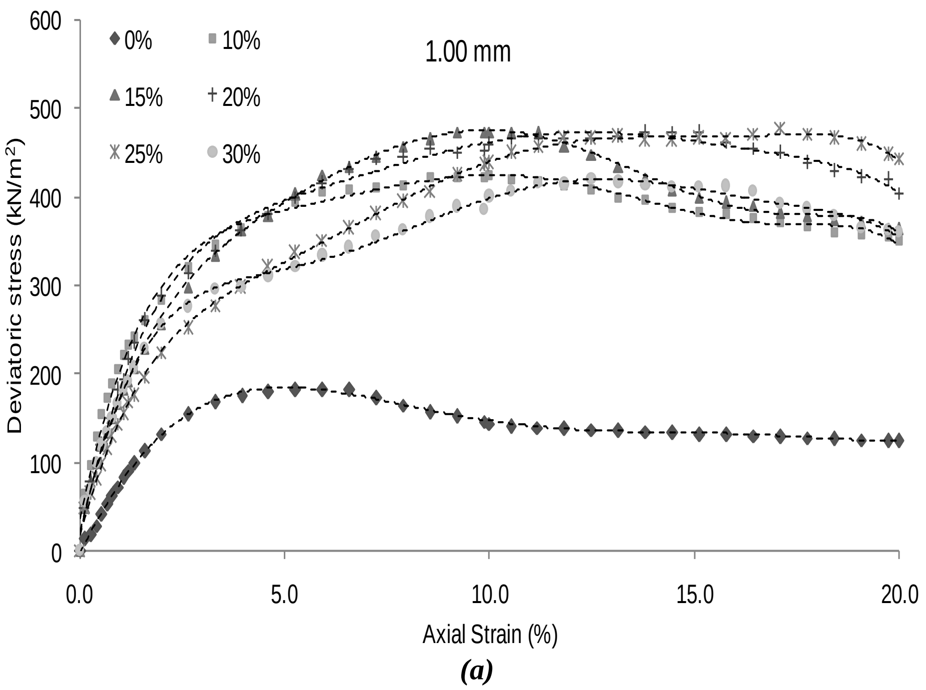


Figure 5: Variation of friction angle for different rubber sizes and proportion of mix

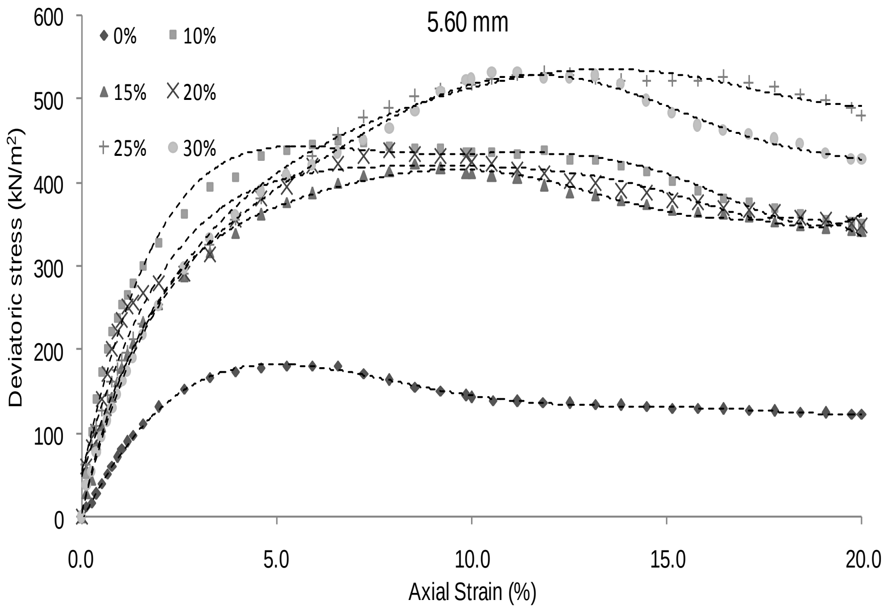
Figure 5 shows frictional angle estimated from direct shear tests for different percentage and size of tire crumbs. It is observed that by adding rubber crumbs of up to 25% will increase friction angle and then decreases slightly with further addition, but still larger than that of sand alone. The friction angle in present study varies from 32^o to 44^o for sand with 25% rubber mix for 5.60 mm size. The increase can be explained by the fact that sand particles filled up the voids in the mixture and thus enhancing the friction angle. But for different sizes of rubber, increase in initial friction varies slightly. These variations of friction angle with different sizes are shown in Figure 5. Slight increase in friction angle for 1.00 mm and 5.60 mm is due to the friction mobilized between sand-rubber interface are slightly greater than other two mixtures with different sizes of rubber. This led to the increase of friction angle, while adding rubber particles more than 25% in mixtures would lead to the decrease of friction angle, as more percentage of rubber may create more voids in the mixture. Thus friction angle is mainly controlled by the rubber grains in the sand-rubber mix (Ghazavi, 2004). Cohesion intercept was also observed for samples containing rubber mix. It increases with increase in rubber content due to significant interlocking effects.

4.2 Unconsolidated undrained triaxial test

Typical trends of stress-strain curves obtained from UU triaxial tests for confining pressure of 100 kN/m^2 for different size and percentage of tire crumbs are shown in Figure 6. The influence of rubber content could be noticed by the significant change in the stress-strain behaviour. Peak strength, ultimate behaviour, toughness and ductility were enhanced with increasing rubber content. In contrast to the behaviour observed in direct shear test, size and percentage of tire crumbs strongly influenced the shear strength characteristics of sand, with increasign normal stress. The same trend is observed in UU test also.



(a)



(b)

Figure 6: Stress-strain curves for confining pressure of 100kN/m^2 for different rubber size: (a) 1.00 mm, (b) 5.60 mm

4.2.1 Failure and ultimate behaviour

The effects of confining pressure for 5.60 mm tire crumb mix on deviatoric stress (q_f) at failure and on ultimate deviatoric stress (q_{ult}) are presented in Figures 7 and 8. It can be seen that increase in rubber percentage results in increase in q_f and q_{ult} up to rubber percentage of 25% and beyond which these values decrease. As expected, values calculated for 2 mm and 4.75 mm STCM were slightly smaller, but the increase in q_f and q_{ult} against rubber percentage was also noted. The effect of confining pressure is clearly indicated by the strength envelopes. The peak

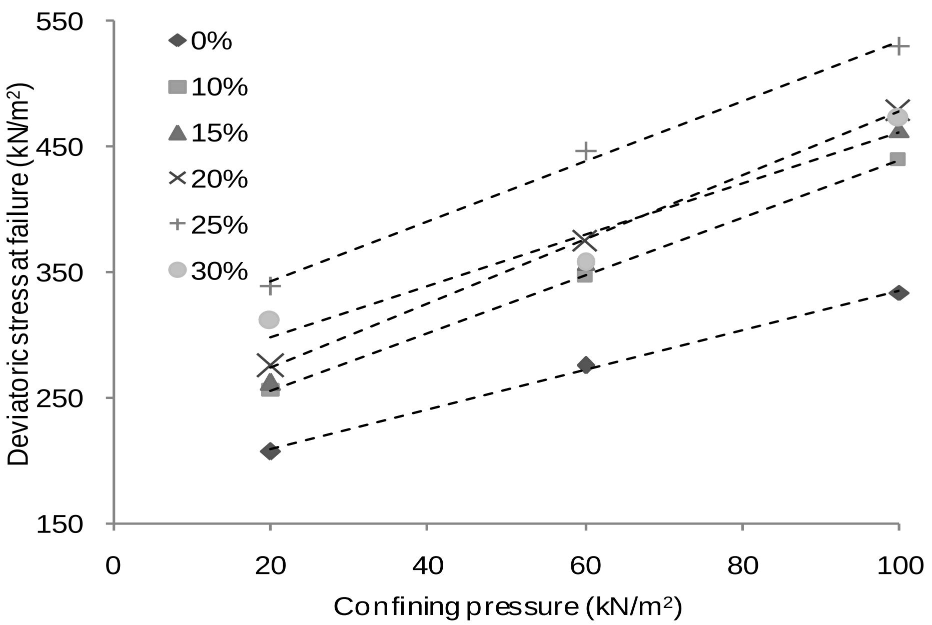


Figure 7: Effect of 5.60 mm rubber on deviatoric stress at failure for different composition

friction angle of sand increases from 32° to 46° for 25% mix ratio of 5.60 mm size. As expected, the cohesion intercept was also affected by rubber mix.

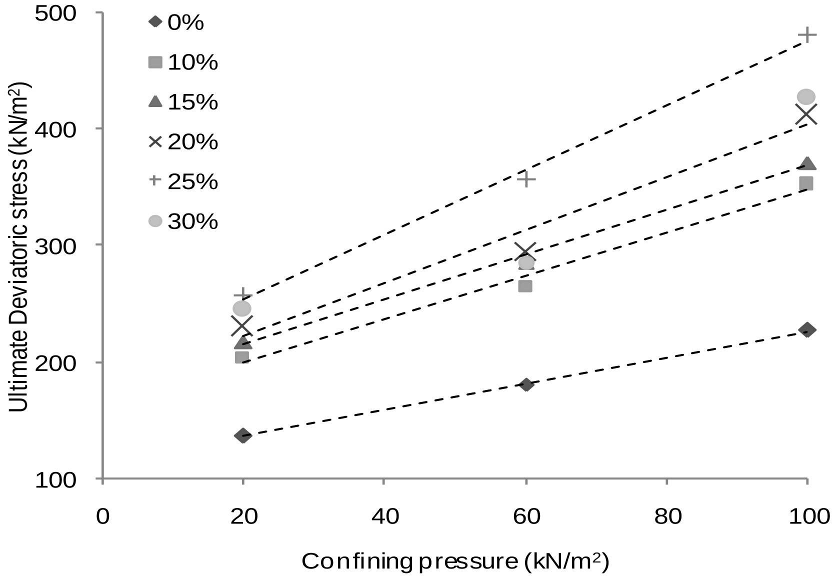
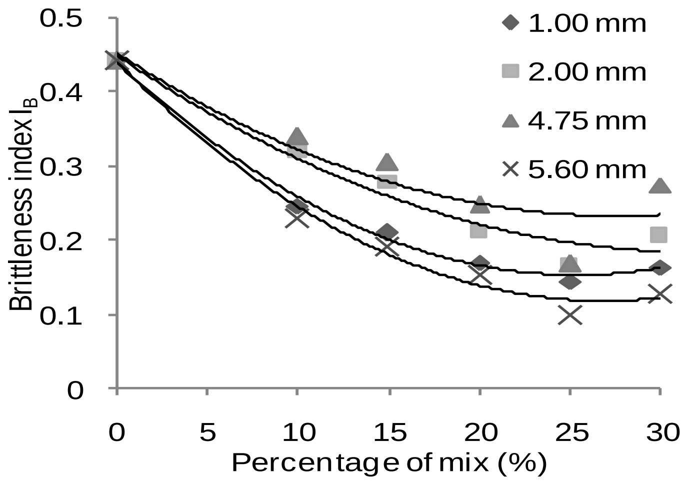


Figure 8: Effect of 5.60 mm rubber on ultimate deviatoric stress for different composition

4.2.2 Ductility

The most promising advantage of scrap tire crumb as a composite engineering material is the improvement of ductility and energy absorption capacity of the mixture. The measure of this behaviour is given by the brittleness index (I_B). I_B is a function of q_f and q_{ult}. As the index decreases towards zero, failure mechanism becomes more ductile. As shown in Figure 9, brittleness index of sand decreased with increasing percentage of rubber, but increased with decrease of confining pressure.



(c)

Figure 9: Typical plot of variation of brittleness index of sand with inclusion of rubber for confining pressure of 100 kN/m²

4.2.3 Energy absorption capacity

Stress-strain curves obtained from UU test for different confining pressure have been used to estimate toughness by measuring the area under stress–strain curve up to strain level of 20%. Typical plot of energy absorption capacity values is shown in Figure 10. It is shown that the energy absorption capacity increases with increasing rubber content which is due to the increase in peak and ultimate stresses. The same trend could be observed in composite for all sizes of rubber, and slightly lower for mixtures with 2 mm and 4.75mm rubber particles.

STCM increases friction angle and shear resistance for composition up to 25% of rubber by volume, while cohesion intercept increases. The same trend is observed for toughness and ductility characteristics in the UU tests as well. Though, the trend remains the same for all four sizes, but it starts decreasing slightly for 2.00 mm compared to 1.00 mm. However, it starts increasing for the other two sizes (4.75 and 5.60 mm).

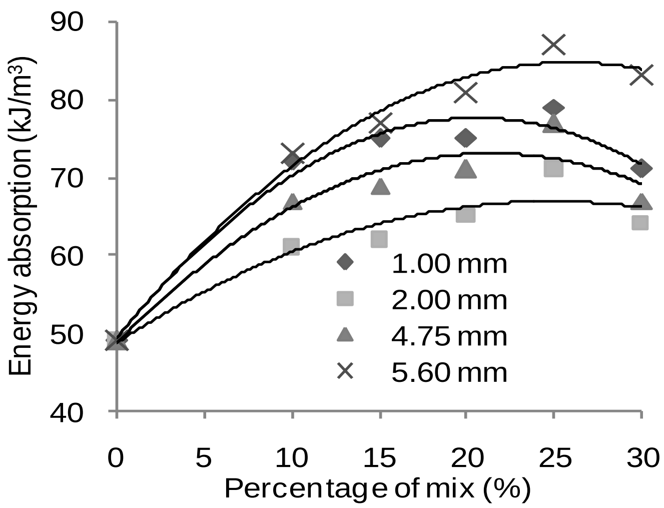


Figure 10: Typical plot of variation of energy absorption capacity of sand with inclusion of rubber for confining pressure of 100 kN/m^2

5. Summary and conclusion

It can be concluded that the shear strength and initial friction angle are significant for mixtures with 25% rubber of any size. These findings are matched with results of Black and Shakoor (1994) and Ghazavi (2004). In present study, the optimal size of rubber is 5.6 mm, with 25% by volume. These results can be used for effective design of STCM seismic isolation system for low-medium rise building.

Based on the results obtained from the experimental studies, the following conclusions can be drawn:

1. For all sizes of tire crumb, parameters influencing shear strength characteristics, energy absorption and brittleness index were tire crumb size, percentage of tire crumb, normal stress and confining pressure.

2. The addition of tire crumbs to sand significantly increased peak shear strength. The cohesion intercept was also increased slightly with increasing rubber content. But, friction angle decreases with higher than 25% rubber by volume.

3. The shear strength of sand increases with addition of rubber crumbs. Also, addition of tire crumbs consistently improved friction angle from 32^o to 46^o.

4. With increase in shear strength characteristic, toughness measured by energy absorption capacity and ductility were also increased for all tire crumb sizes.

The shear enhancement by adding rubber crumbs increases with the percentage of rubber and starts decreasing after 25% rubber by volume. This trend is observed for all sizes of tire crumbs from direct shear test.

5. Maximum efficiency of STCM for different sizes of rubber is observed for crumb size of 5.60 mm, followed by 1.00 mm, 4.75 mm, and 2.00 mm. Maximum friction was obtained for 5.60 mm and 1.00 mm.

6. For 25% rubber content with rubber size of 5.60 mm, it is observed that a reduction of brittleness index and an increase in energy absorption capacity by about 50% compared to that of sand for all confining pressures.

7. The static test results would be useful for selecting efficient crumb size and composition for dynamic test in future.

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