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Effect of Geogrid Reinforcement on Shear Strength Characteristics of a Rubber-Sand Mixture under Undrained Triaxial Test

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ABSTRACT

Utilization of rubber-sand mixtures as construction materials, such as lightweight filling materials, embankment construction, seismic isolation materials, … etc., provides significant advantages, as scrap tires induce environmental issues. In this study, unconsolidated undrained triaxial tests were performed to examine the shear-strength characteristics of geogrid-reinforced sand-rubber mixtures. The rubber percent (10%, 20%, 30%, 40%, 50% and 60%), the confining pressure of the cell (19.6 kPa, 49 kPa and 98 kPa) and the number of geogrid reinforcements (1 to 4) were varied for investigating the impact of these parameters. The relative density of sand remained constant (80%) during the test. The test results were evaluated in terms of the stress-strain characteristics of rubber-sand mixtures. The test findings demonstrated that by increasing the confining pressure of the cell, the same rubber-sand mixtures with the same relative density and rubber content take more loads. The peak stress of unreinforced rubber-sand mixtures increased with the increasing proportion of rubber content up to 30%, beyond which it decreased as rubber content increased. Maximum peak stress and axial strain have been achieved with 50% of the rubber content and four layers of geogrid reinforcement. The brittleness index of the rubber-sand mixture reduces when geogrid reinforcement is added. The minimum brittleness was found to be 0.042 at 50% rubber content with three layers of geogrid reinforcement.

KEYWORDS: Geogrid, Shear strength, Triaxial test, Rubber-sand mixture, Soil reinforcement.

INTRODUCTION

Ground vibrations that may cause excessive strain in structures are not desirable, because structural stability and durability are significantly affected. Construction in these conditions is very challenging for geotechnical engineers, because structures can collapse. Structures can withstand the acceptable limit of vibration; after that, the structure becomes hazardous. Vibration can be reduced by enhancing the damping capacity of structures and building materials. The viscosity and elastic properties of rubber make it an excellent shock-absorbing material (Tsang et al., 2012). The quantity of old tires is continuously increasing due to that vehicles in both developing as well as developed countries continue to increase. According to a study on the global tire-recycling market (2020), about 1.6 billion tires are manufactured annually and about one billion of these end up in landfills each year. The recycling sector, on the other hand, only processes 100 million tires per year. This massive amount of waste tires creates human-health, environmental and disposal problems. Some present recycling practices have a harmful influence on the environment. The dampening capabilities of granular rubber chips produced from discarded tires can still be fully utilized in the civil-engineering field. The high permeability, compressibility, strength and deformation of waste tires, including granular rubber, tire shreds, tire chips, … etc., make these waste tires be considered smart geomaterials (Neaz Sheikh et al., 2013). Possible alternatives for reusing discarded tires are vibration reduction and seismic isolation of structures, utilizing significant dampening properties of rubber (Senetakis et al., 2012; Tsang et al., 2012).

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There have been several studies conducted in recent decades to investigate the benefits of rubber aggregate as a lightweight backfill geomaterial for embankments (Edinçliler et al., 2010; Lee et al., 1999; Yoon et al., 2006; Zhang et al., 2018). Several researchers have reported that sand reinforced with tire chips has better frictional angle, shearing resistance and stability as compared to sand alone Combinations of dense sand having 30% rubber chips by volume (Anbazhagan et al., 2017; Attom, 2006; Li et al., 2020; Rouhanifar et al., 2021; Yang et al., 2020) have been used. However, there have been few systematic studies available that reported the use of rubber-sand mixtures for vibration isolation (Chew and Leong, 2019; Das and Bhowmik, 2020; Senetakis et al., 2012; Shariatmadari et al., 2018).

Most of the literature reported that the bearing capacity of rubber-sand mixes decreases as the rubber content exceeds 30% by volume. To overcome this problem, geogrid is placed within rubber-sand mixtures for improving ductility, strength, deformation, … etc. properties of sand. The primary function of geogrids is to enhance soil engineering properties. Geogrid reinforcement has been increasingly applied in various geotechnical-engineering fields to strengthen bearing capacity and minimize soil settlement (Patra et al., 2005; Shrigondekar and Ullagaddi, 2021; Sitharam and Sireesh, 2004; Xu et al., 2019). Manohar and Anbazhagan (2021) reported that geosynthetic-reinforced rubber-sand mixtures improved shear strength at a higher content of rubber.

An undrained triaxial test is used in this study to investigate the impact of geogrid reinforcement on the deformation and shear-strength behavior of a rubber-sand mixture. The number of geogrid layers, rubber content and confining pressure of the triaxial cell were varied to obtain the optimal usage of geogrid-reinforced rubber-sand mixtures.

MATERIALS

Sand

The current study used river sand which is available in the area of Begusarai district (Bihar, India). The index properties of sand; namely, specific gravity, friction angle, coefficient of uniformity, coefficient of curvature and minimum and maximum dry density, were determined in the laboratory. The specific gravity of sand was found as per ASTM D854 (2002). In accordance with the unified soil classification system (USCS), ASTM-D2487, the soil is characterized as poorly graded sand (SP) (ASTM, 2017). Table 1 depicts the physical properties of sand.

Table 1. Physical characteristics of sand

Physical Properties	Value
Color	Reddish-brown
Specific gravity (G)	2.70
Minimum dry density (γ_{mim})	14.47 kN/m^3
Minimum dry density (γ_{max})	17.91 kN/m^3
Effective size (D_{10})	0.2 mm
Coefficient of uniformity (C_u)	3.32
Coefficient of curvature (C_c)	0.95
Frictional angle (ϕ)	41°

Geogrid

In the current investigation, a biaxial geogrid comprised of polypropylene material was utilized. The size of the aperture in the geogrid measured 30 mm x 30 mm. The tensile properties of the geogrid were determined in accordance with ASTM-D6637-2011. Table 2 lists the characteristics of the geogrid.

Table 2. Properties of geogrid

Properties	Value
Aperture (mm)	30 x 30
Failure strain (%)	11
Secant modulus at 5% strail (kN/m)	240
Ultimate tensile strength (kN/m)	20

Rubber

The waste tire rubbers were collected from the local scrap metal factory (Begusarai, Bihar, India). These scrap rubber tires were cut into angular pieces and powder form in different sizes. As per ASTM D6270, granular rubber is considered rubber with particle sizes ranging from 425 microns to 12 mm, while ground rubber was with a size range of 425 microns to 2 mm and rubber powder was with a size less than 425 microns. Tire chips were with particle sizes ranging from 12 mm to 50 mm and tire shreds were with particle sizes ranging from 50 mm to 300 mm (ASTM D6270). Sieve analysis was performed to segregate these rubbers into different groups as per grain size.

EXPERIMENTAL PROGRAM

The volumes of sand and rubber required to prepare their mixtures were determined for all groups of rubber. These mixtures have been prepared at the rubber percents of 10%, 20%, 30%, 40%, 50% and 60% by volume concerning the total volumes of mixtures. The quantities of rubber and sand were taken by volume, because volumetric measurement is easily implemented on site. Though, samples were prepared in the laboratory by taking the weight measurement which was calculated by knowing the volumes and specific gravities of the materials. The mixture was uniformly mixed using the hand mixing technique by taking the required amounts of rubber and dry sand. This mixture was poured in four equal layers in the triaxial mould and each layer was slightly compacted. Figure 1 illustrates the triaxial test arrangement employed in the current study. The unconsolidated undrained (UU) tests were performed in a cylindrical mould 100 mm in diameter and 200 mm in length. A load cell of 50 kN capacity was utilized to measure the failure load. To record the strain, an LVDT of 50 mm capacity was mounted on the triaxial machine. The required amount of confining pressure was applied to the sample around 15 minutes before shearing to stabilize the sample. The sample was then subjected to a constant strain rate of 1.25 mm/min until it failed or the axial strain reached 20%, whichever occurred first.

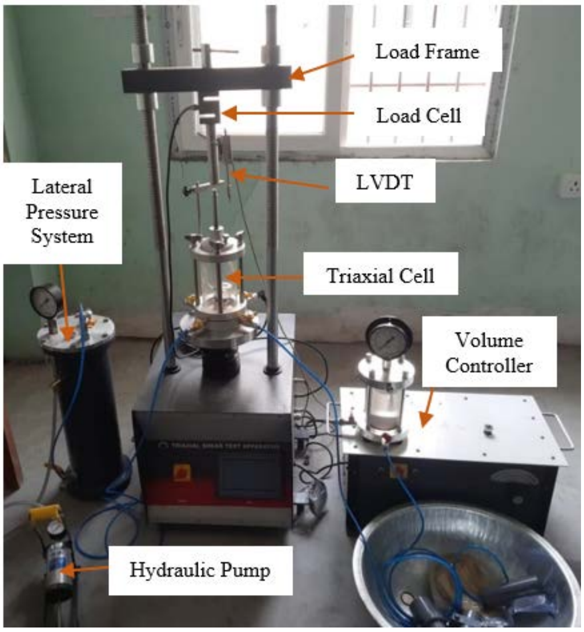

Figure (1): Triaxial test setup utilized in the present research

The geogrid was placed horizontally with a different number of layers in the rubber-sand mixture, as shown in Table 3. The spacing of the geogrid was kept H/2, H/3, H/4 and H/5 for one layer, two layers, three layers and four layers of geogrid, respectively. The geogrid size was kept relatively slighter than the diameter of the soil specimen.

Table 3. Triaxial testing program

Series	Configuration	Constant Parameters	Variable Parameters
Series I	Sand-rubber mixture	Relative density of sand = 80%, Strain rate = 1.25 mm/min	Rubber content (%) = 10, 20, 30, 40, 50, 60 Confining pressure (kPa) = 19.6, 49, 73.5, 98
Series II	Geogrid-reinforced sand-rubber mixture	Relative density of sand = 80%, Strain rate = 1.25 mm/min	Rubber content (%) = 10, 20, 30, 40, 50, 60 No. of geogrid layers = 1, 2, 3, 4

RESULTS AND DISCUSSION

Two series of unconsolidated undrained triaxial test results were used to demonstrate the shear-strength characteristics of rubber-sand mixtures. The impacts of confining pressure and rubber content on shear strength were examined in series I, while the impact of geogrid on the rubber-sand mixture was investigated in series II.

Stress-Strain Behavior of Sand-Rubber Mixtures under Various Confining Pressures

Laboratory triaxial tests were performed on rubber-sand mixtures with confining pressures of 19.6 kPa (0.2 kg/cm^2), 49 kPa (0.5 kg/cm^2), 73.5 kPa (0.75 kg/cm^2) and 98 kPa (1 kg/cm^2). Figure 2 shows a typical trend of stress-strain curves produced under the unconsolidated undrained triaxial test with various confining pressures at 30% rubber content and 80% relative density of sand.

From this figure, it can be noticed that by raising the confining pressure of the triaxial cell, the sand-rubber mixtures with the same relative density and the same rubber content could take more loads. With a cell pressure of 98 kPa, the same soil with the same relative density and rubber content could withstand approximately 1.65 times more stress than the soil tested with a cell pressure of 19.6 kPa. This may be due to the high confining pressure causing the rubber-sand mixture to become denser, resulting in an improvement in shear strength. Furthermore, the non-linearity of the stress-strain curves revealed that the rubber-sand mixture has a ductile nature, which is a very important parameter from the seismic design point of view.

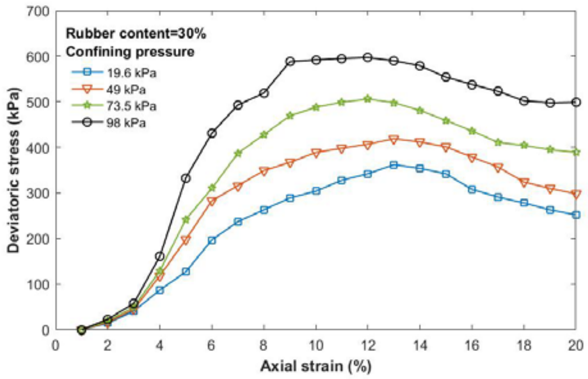

Figure (2): Stress-strain plot of rubber-sand mixtures under various confining pressures

Stress-Strain Behaviors of Rubber-Sand Mixtures Under Various Rubber Contents

Unconsolidated undrained triaxial test results are presented in Figure 3 for unreinforced rubber-sand mixtures at 10%, 20%, 30%, 40%, 50% and 60% rubber content. The confining pressure of the triaxial cell and the relative density of sand were maintained at 98 kPa and 80%, respectively, throughout the test. The rubber content affects the considerable variations in stress-strain behavior, as seen in the diagram. Peak strength and axial strain of sand-rubber mixtures improved with raising rubber percentage up to 30%, then the peak load decreased with increasing rubber content. Peak strength may be reduced at a high rubber content due to a loss of friction angle as well as a change in the mechanical properties of the mixture from brittle to ductile. This may also be because of the reduction in the unit weight of sand-rubber mixtures at high rubber contents. The peak strength is affected by an increase in the amount of rubber at the failure plane. However, under all conditions, the peak stress of rubber-sand mixes is larger as compared to that of clean sand (tire content = 0%). The increased shear strength of the rubber-sand mixes seems to be a result of broader particle size ranges, which creates more voids and results in the rubber-sand mixture being packed more densely. The axial strain that corresponds to the peak-stress growth with the growing percentage of the rubber proportion signifies greater ductility and demonstrates that sand-rubber mixes can be employed as materials beneath foundations for seismic isolation.

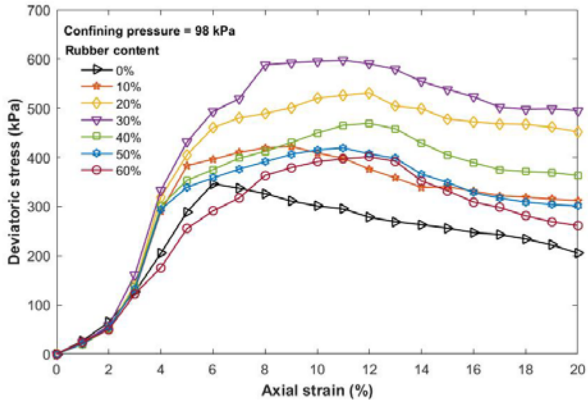

Figure (3): Stress-strain plot of rubber-sand mixtures under various rubber contents

Stress-Strain Behavior of Rubber-Sand Mixtures Reinforced with Geogrids

The impact of geogrid reinforcement on the shear stress of rubber-sand mixes was examined by conducting unconsolidated undrained triaxial tests. The number of geogrid layers ranged from one to four. The geogrid was placed horizontally at the middle (H/2) of the triaxial sample for a single geogrid layer, H/3 and 2H/3 for 2 geogrid layers, H/4, H/2 and 3H/4 for 3 geogrid layers, H/5, 2H/5, 3H/5 and 4H/5 for 4 geogrid layers from the top of the sample, where H is the total length of the triaxial test specimen. Typical stress-strain curves of a single-geogrid reinforcement layer at a 98 kPa confining pressure of the cell with different proportions of rubber content are illustrated in Figure 4. This graph indicates that the peak stress of geogrid-reinforced rubber-sand mixes rises with an increasing percentage of rubber content up to 50%, beyond which improvement in peak strength has not been observed. Thus, the peak stress of rubber-sand mixes was enhanced with the addition of geogrid layers. The improvement in shear strength of rubber-sand mixes at a high rubber percent with the inclusion of the geogrid may be due to the openings in the geogrid interacting with the rubber-sand mixture, confining it and increasing its strength and stiffness.

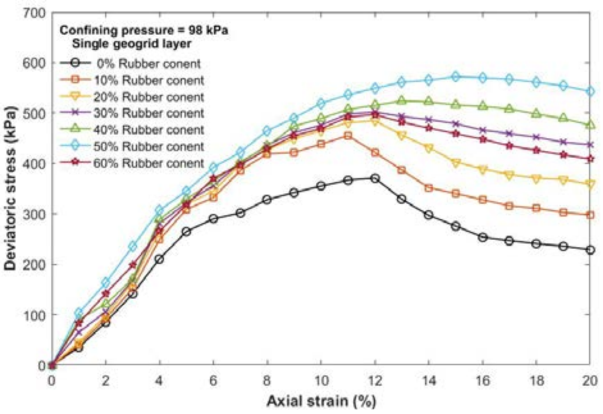

Figure (4): Behavior of geogrid-reinforced rubber-sand mixes under different rubber percents

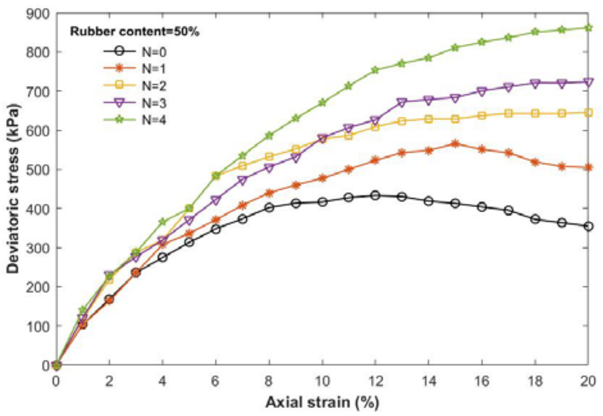

Figure (5): Stress-strain plot of sand-rubber mixtures with various numbers of geogrid layers

Figure 5 illustrates the impact of geogrid reinforcement on the stress-strain characteristics of rubber-sand mixes with a rubber content of 50% and a relative density of sand of 80%. It has been seen from this figure that the number of geogrid layers has a considerable impact on stress-strain behavior. The shear strength of rubber-sand mixtures rises as the number of geogrid layers increases. This can be caused by the interaction between the granular sand and the geogrid layers, which prevents particle mobility and lateral spreading that yields tensile stiffness. The maximum stress of geogrid-reinforced rubber-sand mixes was found to be 877.7 kPa at a strain level of 18% and at four layers of geogrid reinforcement, which is 2.5 times greater than without geogrid-reinforced sand at the same degree of confining pressure. Peal stress and failure stress were achieved at a higher strain level due to the interaction between geogrid layers and rubber-sand mixtures. A higher level of strain in geogrid-reinforced rubber-sand mixtures suggests that the sample is more ductile, which would be a favorable indicator of its ability to withstand seismic loads.

Ductility Behavior of Rubber-Sand Mixtures with Geogrid Reinforcement Layers

The enhancement in ductility as an engineering composite material is a unique advantage of the rubber-sand mixture in comparison with other wastes. Ductility can be measured in terms of the brittleness index (I_B), which is estimated as:

$$I_B = \frac{q_f}{q_{ult}} - 1 \quad (1)$$

where q_f is the failure stress and q_{ult} is the ultimate stress. The failure mechanism becomes more ductile as the brittleness index approaches zero.

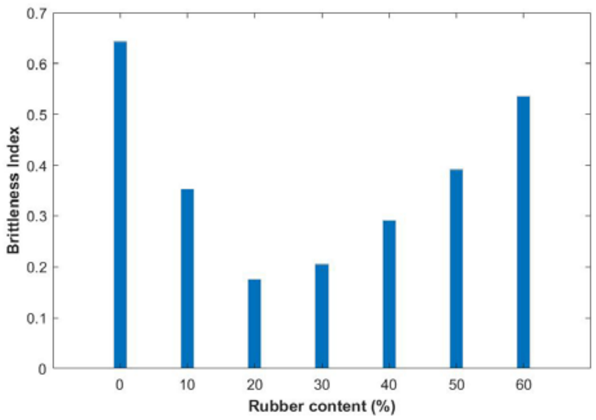

Figure (6): Brittleness index of sand-rubber mixes with different rubber percents

Figure 6 depicts the brittleness index of sand-rubber mixes with various percentages of rubber proportion. It can be seen from this graph that the brittleness index decreased up to a rubber proportion of 20% and after that, it raised. This means that the ductility of mixtures is higher at 20% rubber content. Further adding more rubber content, the ductility of mixtures reduces. The minimum brittleness index was found to be 0.175 at 20% rubber content.

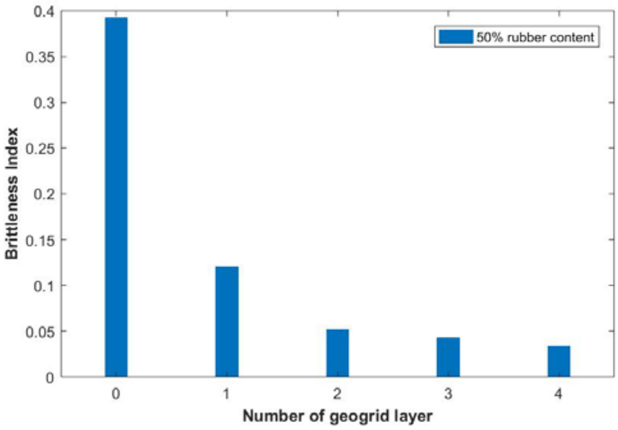

Figure (7): Brittleness index at different numbers of geogrid layers with 50% rubber content

The brittleness index of geogrid-reinforced rubber-sand mixtures at 50% rubber content with different numbers of geogrid layers is illustrated in Figure 7. The brittleness index dropped with the addition of more geogrid layers, as can be seen in the diagram. This means that the application of geogrid reinforcement improves the ductility of sand rubber mixes. This is because the geogrid-reinforced rubber-sand mixture bears more stress. As a result, the sample takes more time to fail. The minimum brittleness index was found to be 0.042 when three layers of geogrid reinforcement were used.

CONCLUSIONS

Laboratory triaxial tests were performed on geogrid-reinforced rubber-sand mixtures to investigate the impacts of rubber percent and number of geogrid reinforcement layers on the strength behavior of the mixtures. The following are the key conclusions:

1. The confining pressure of the cell influences the stress-strain behavior of rubber-sand mixtures. Rubber-sand mixtures that have a higher confining pressure have been found to resist a greater load.
2. The proportion of rubber percent in rubber-sand mixtures has a great influence on stress-strain behavior. Peak stress raises with increasing rubber percent up to 30%, after which peak stress declines.
3. The peak strength of a geogrid-reinforced rubber-sand mixture improves as the proportion of rubber percent increases up to 50%, after which no improvement in peak strength has been observed.
4. The number of geogrid reinforcement layers influences the peak stress, axial strain and ultimate stress of a rubber-sand mixture. Maximum improvement in the rubber-sand mixture has been observed when four layers of geogrid reinforcement were used.
5. The brittleness index of rubber-sand mixtures is lowered by incorporating geogrid reinforcement. Maximum ductility was found at three layers of geogrid reinforcement.

The results of this study demonstrate that geogrid-reinforced rubber-sand mixtures may be employed as materials for seismic design, lightweight filling materials and other applications. In this way, huge amounts of waste tires will be easily utilized all over the world. Utilizing waste tires in large amounts will reduce significant disposal expenses as well as potential degradation of the environment and aesthetics.

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