3rd Conference on Sustainability in Civil Engineering (CSCE'21)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

Experimental investigation of shear strength of sand mixed with tire shred

[a]Farhan Ahmad, [b]Muhammad Anwar, [c]Arshad Jamal*, [b,d]Mudassir Iqbal

a: Department of Civil Engineering, University of Engineering and Technology, Taxila, Pakistan.
Email: engrfarhan51@gmail.com
b: Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan.
Emails: 15pwciv4287@uetpeshawar.edu.pk; mudassiriqbal@uetpeshawar.edu.pk
c: Department of Civil and Environmental Engineering, King Fahd University of Petroleum and Minerals, KFUPM, PO BOX 5055, Dhahran 31261, Saudi Arabia.
d: Shanghai Key Laboratory for Digital Maintenance of Buildings and Infrastructure, School of Naval Architecture, Ocean and Civil Engineering, Shangai Jiao Tong University, Shanghai, China.
* Corresponding author: Email ID: arshad.jamal@kfupm.edu.sa

Abstract- The rapid increase in industrialization, urbanization, and modernization has significantly increased the scrap tire production rate. The innovations, advancements, and continuous up-gradation of the technological products also enhance its production rate, making it one of the emerging waste streams in the world. About 13.5 million tons of scrap tires are generated every year around the globe. Scrape tires significantly damage the environment because of their complex degradation process. In this research work, the shredded scrap tires of different sizes (i.e., 50mm, 75mm, and 100mm) are introduced to the sand for investigating its shear strength characteristics, which is utilized in earth embankment, mechanically stabilized walls (MSE) and landfill. In this study, an attempt is carried out to examine the shear strength properties of the sand mixed with various sizes of tire shred by using large-scale direct shear test apparatus in order to investigate the optimum values of tire shred size as well as the mix ratio of sand tire mix at which maximum shear strength is obtained.

Keywords-tire shred, mixing ratio, shear strength**,** large scale direct shear test

1. Introduction

Waste materials like scrap tires, rubbers, plastics, glass, etc., are usually produced in every society. These wastes are usually disposed to the landfill, which is a menace to the global environment and causing serious problems. Every year over 13.5 million tons of scrap tires are produced globally. The accumulation of these tires in huge amounts can damage the environment because of its difficult degradation process relative to other waste streams. The adverse effect of waste scrape tires includes environmental degradation, fire, effect the agricultural growth of plants, and ill effects on human health. In order to tackle this problem and to utilize these scrap tires, one of the effective ways is to utilize these scrap tires as an aggregate in the construction industry. The utilization of shredded scrap tires as an aggregate has the most significant advantages, such as 1) lightweight having density ranges from 500 to 1040 kg/m^3 .2) Good drainage. 3) Low earth pressure. 4) Improve the shear strength of sand when incorporated owing to the mechanical properties of rubber[1-5]. As a result of these advantages, tire shreds are widely utilized in many applications like slope stability structures, landfill covers, road embankment, retaining wall backfill etc. In the current study, the shredded tires are utilized to enhance the shear strength characteristics of sand. The two parameters on which shear strength primarily depends are cohesion and friction angle. The binding effect of soil grain results from cohesion, whereas friction angle is owing to friction between soil particles. The mathematical relation representing the shear strength of soil is given by $s = c + \sigma \tan \theta$. Where "s" and "σ" indicate total shear stress and normal stress, whereas "c" indicates cohesion and "θ" indicates internal friction angle. It is found that for pure, clear sand, cohesion is zero so shear strength also is zero at zero confining pressure, whereas shear strength values range from 0.5 to 2 kPa for unclear sand. Also, shear strength is about 200 kPa for highly plastic clay, while for medium plastic clay, it is between 10 to 100 kPa. So, by utilizing sand in a certain project where shear strength is also the major concern, one should improve the shear strength characteristics because of the reasonable lower shear strength of sand. It has been examined that by incorporating elastic materials such as small pieces of scrap tires in sand reasonably improves its shear strength[5-7].

Ghazavi et al.[8] utilized scrap tire in filling areas. The study found that the utilization of the scrap tire buried form/ filling area is more beneficial because of its combustible nature and low lateral pressure due to its light nature. Yoon et al. [9]found that the tires being lightweight aggregates, can be utilized to construct embankment due to their lower backfill pressure and high strength. Bernal et al.[10] found that the incorporation of scrap tires in sand produces reinforcement and enhances its shear strength compared to sand alone. The study reported that at 30%, tire shred by volume resulted in the friction angle of 65.8 degrees, whereas the friction angle of pure sand 34.8 degrees. Humphrey et al. [11, 12] investigated that sand tire mixture can undergo significant compression at low normal pressure. The study reported that when tire shred experiences load, their compressibility decreases because the compression in tire shreds is mainly plastic. Thereby, to reduce plastic compression, preloading can be done when it has been filled. Edil et al. [13] investigated that when 10% of scrap tire shreds by volume are introduced in the sand, it significantly enhances its shear strength. Bali et al. [14] investigated the effect of tire chips in different percentages on the shear strength characteristics of sand. Locally available tire chips of size 20x10 mm were utilized and found that significant improvement in sand shear strength was observed when tire chips up to 40% by weight were incorporated in the sand. It was reported that shear strength properties were improved up to 30% as compared to pure sand. Rkaby et al. [15] examined the influence of varying percentages of granulated rubber on the shear strength properties of sand. The percentage by weight of granulated rubber mixed with sand ranged between 0 and 50%. The shear strength of sand was reported to increase by increasing the granulated rubber contents up to 20% compared with pure sand, followed by a gradual decrease in the shear strength of sand for granulated rubber percentages between 30-50%. From the brief assessment of the current literature review, it is concluded that utilization of shredded scrap tires aggregates in the construction industry is a viable solution to effectively utilizing these waste tires effectively thereby reducing the hazardous material from the environment. Also, from the literature review it is concluded that the influence of shear strength on the sand tire mixture depends upon the shape, size and texture of tire shreds, tire shreds content, mixing ratio, confining pressure and normal stress. The current study aims to investigates the shear strength characteristics of sand when various sizes of tire shreds (i.e 50mm, 75mm and 100mm) are incorporated at different percentages. The study also aims to investigate the optimum tire shred size and mixing ratio at which maximum shear strength is obtained.

2 Materials and Methods

2.1 Materials

Materials mainly used in this research work include sand and tire shreds. For sand, Sieve analysis was carried using standard stated procedures (shown in Figure 1(a)). Locally available sand was utilized, passing through a 4.75mm sieve and retaining on 0.075mm sieve. The sand was classified as well-graded sand according to the Unified Soil Classification System (USCS), ASTM-D2487[16]. The specific gravity of sand used in the analysis was 2.67. For mixing tire shreds with sand, the scrap tires were cut into pieces of various sizes of length (50mm, 75mm, and 100mm), whereas the width of tire shreds was kept constant at 5mm for all samples. These tires were mixed with sand in various ratios, as shown in Table 1. Figure 1(b) indicates the sand tire mixture.

Table 1- *Sand-tire shred mixing ratios*

S/No	Tire Size (50 mm)	Tire Size (75 mm)	Tire Size (100 mm)
1	20/80	20/80	20/80

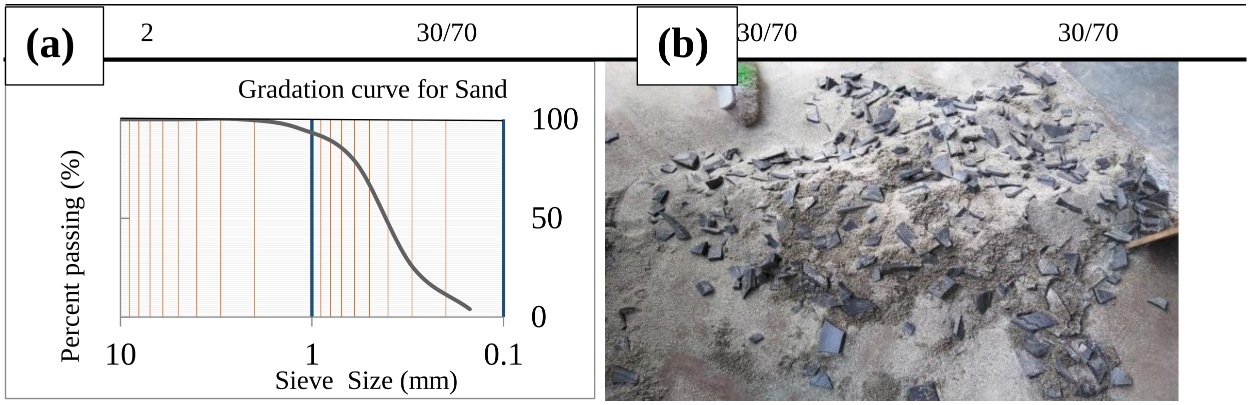


Figure 1: *(a) Gradation curve of sand. and (b) Sand-tire mix.*

2.2. Experimental Setup and Sample Preparation

The apparatus used for the large-scale direct shear test is shown in Figure 2(a). The apparatus consists of two shear boxes upper and lower shear boxes whereas the dimension of the upper shear box is 2ft x 2ft x 1ft (600mm x 600mm x 300mm), and that of the lower one is 2ft x 2.5ft x 1ft(600mm x 750mm x 300mm). The upper shear-box is fixed while the lower shear box is movable and can shear over the upper shear box. To avoid friction among the two boxes, lubricant is used. Normal and shear forces are applied with hydraulic jacks. Horizontal shear force is applied on lower boxes, and normal vertical load is applied on the upper shear box shown in Figures 2 (b) and (c), respectively. The base plate was used for the uniform distribution of normal load. A horizontal load cell is connected to the lower boxes, which can measure horizontal shear displacement, where is vertical load cell is connected at the top of the upper box, which measures vertical displacement. The experimental setup for the shear test is presented in Figure 2(a).

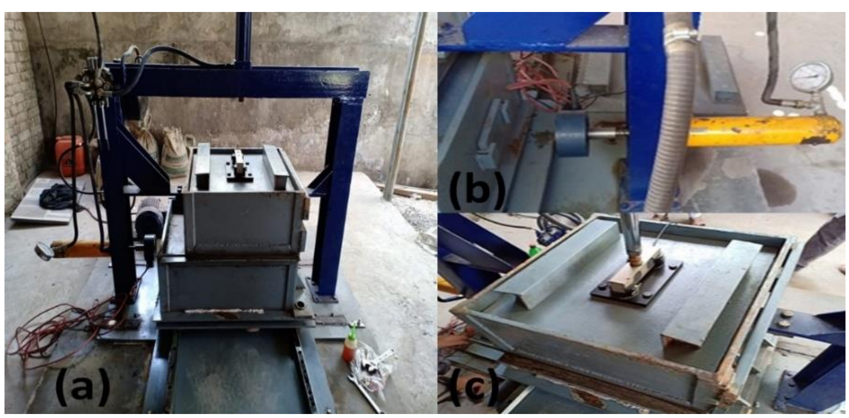


Figure 2: *(a) Experimental setup for large-scale direct shear test. (b) Hydraulic Jack (Horizontal loading). (c) Hydraulic jack (Vertical Loading)*

2.3 Experimental program

To find shear strength properties of the sand-tire mix, large-scale direct shear tests were performed. For this purpose, a number of tests are performed on the sand-tire mix and on sand alone is shown inTable 2. First three tests were performed only on pure sand, and the rest were performed on the sand-tire mix. Tires of different sizes, i.e., 50mm, 75mm, and 100mm, were used in combination with sand. Before performing the test, a modified proctor has been performed on the sand-tire mix in order to determine the compaction test ratio of maximum dry density, which was used as a reference for the shear test.

2.3.1 Direct Shear Tests for Pure Sand Mixes

During the first phase, tests were performed on pure sand in order to study the shear strength characteristics of pure sand before performing on the sand-tire mix. Upper and lower boxes are filled with sand and then compacted sand in each shear box. First of all, a normal-vertical load is applied on the base plate of the upper box, and after the application of the normal-vertical load, the horizontal load is applied on the lower box. To determine shear displacement horizontal transducer is attached to the lower box. Horizontal load is applied on the lower box, and the resulting displacement is measured by a load cell, as indicated in Figure 2(b). Similarly, the normal vertical load is exerted on upper boxes, and the corresponding displacement is measured by the vertical load cell, as shown in Figure 2(c). Three tests were performed on pure sand in normal load. The first test was conducted at 20kN, the second at 30kN, and finally, the third set of tests were performed at a load of 40kN. And in each case, data is collected by the data logger. After plotting the data, we get the shear strength properties of pure sand under different normal loads.

2.3.2 Direct Shear Tests for Sand-Tire Shred Mixes

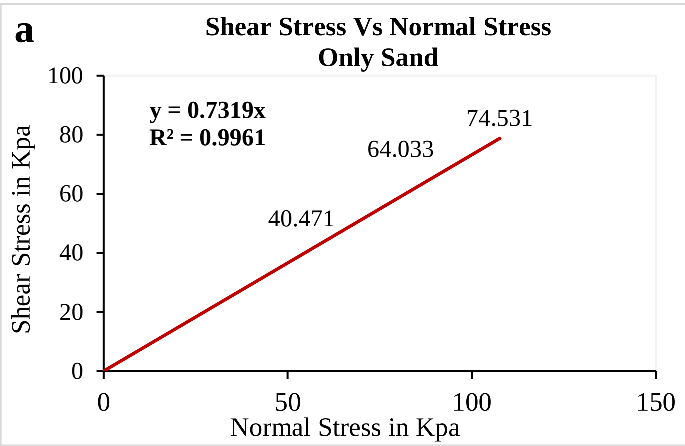
After performing tests on pure sand, tests were conducted on sand–tire mix. First of all, sand is mixed with 50mm tire shred size, and tests were performed under different normal loading, i.e., 20kN, 30kN, and 40kN, respectively. After that, 50mm and 75mm tire shred sizes were mixed with sand in various ratios, and tests were performed, respectively. Table 2 shows the details of the tests which were performed.

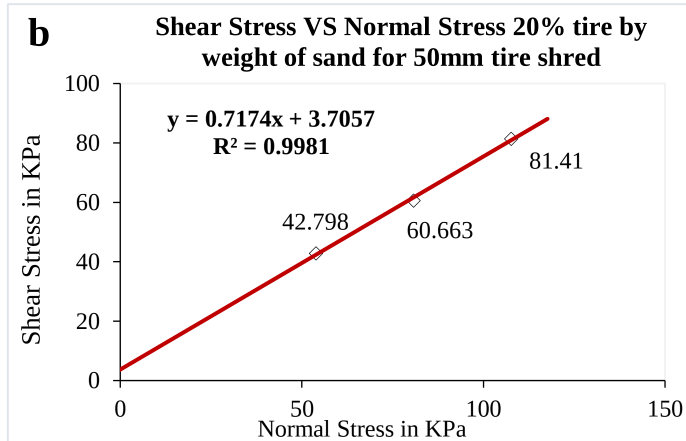
Table 2*- Details of Large-scale Direct Shear Tests*

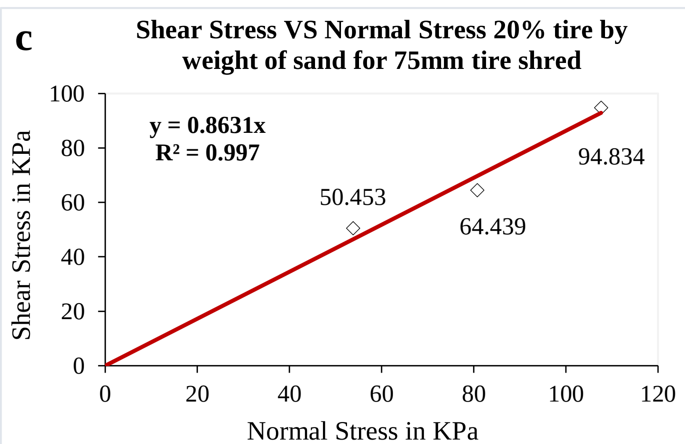
S/No	Tire Size (mm)	Mixing Ratio (Tire/Sand)	Normal Load (KN)
1	-	Only Sand	20,30,40
2	50, 75, 100	Sample with Maximum Dry Density	20,30,40

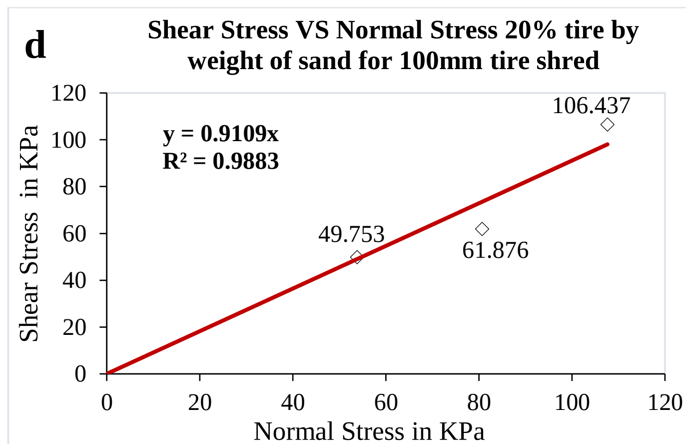
3 Results and discussion

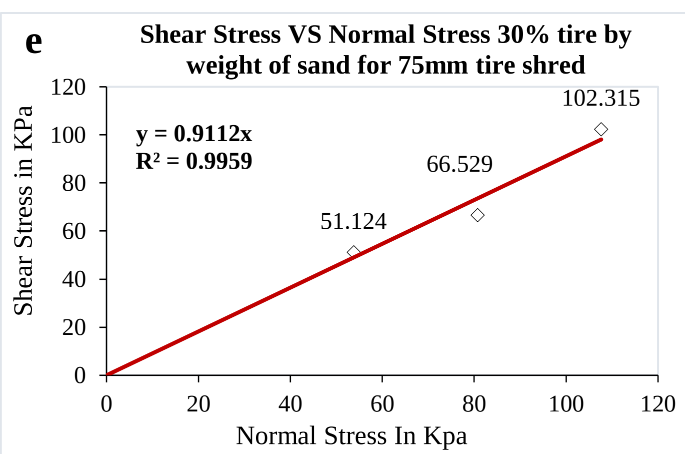
As the shear strength of soil depends on shear strength parameters that are a,) Friction angle b) Cohesion. Increasing these two parameters will enhance the soil shear strength. The Graphs are shown in Figure 3(a-g), which indicates the effect of normal stress on shear stress of pure sand as well as sand mixed with tire shred in different proportions. From the results shown in Figure 3 and Table 3, it may be noted that increasing the ratio of tire shred is accompanied by corresponding friction angle increases, increasing the shear strength of sand tire mix. However, a decrease in shear strength at higher tire chip/shreds ratios and size occurs because of the segregation phenomena which happens in the sand tire mix during its compaction; the sand and tire shreds particles separate from one another as a result instead of compaction bulging occurs which cause a decrease in shear strength. Also, using tire shred in suitable proportion will increase the friction between the sand and tire, which also accounts for an increase in shear strength of the sand-tire mix. Figure 4 indicates the variation of angle of internal friction with both percentages of tire shreds and their sizes. It may be noted from Figure 4 that angle of internal friction increases with increase in size and percentages of tire shreds with attaining a maximum value for 100mm tired size with a mix ratio of 20%. Any increase in the percentage of tire shred would lead to a reduction in value of the angle of internal friction. From the test results, the friction angle for pure sand is measured as 32 and the corresponding shear strength is 75 kPa. Whereas for sand tire mix, the friction angle obtained is 46˚, and the corresponding shear strength is 106 kPa, as shown in Table 3. So it means that using tire shred in suitable proportion with sand significantly enhances the shear strength of the soil. Also, from Table 3, it can be noted that friction angle and shear strength reach maximum values, i.e. (106 kPa and 46˚) and then start to decrease with further increase in percentage and size so it can be concluded that sand tire mix attains maximum shear strength using optimum values of tire shred size and percentage.

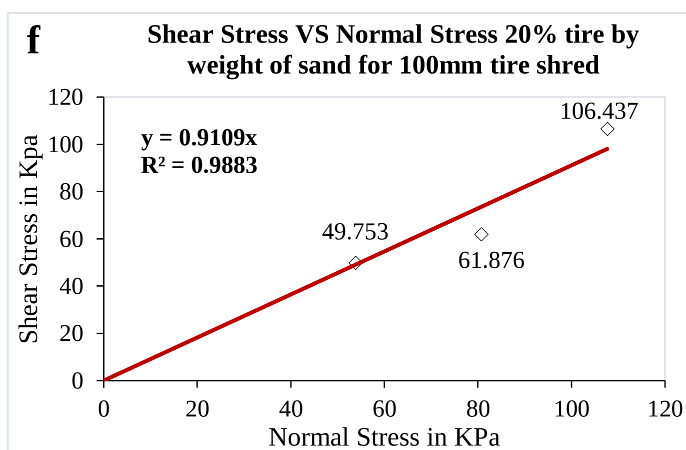

a
Shear Stress Vs Normal Stress
Only Sand
y = 0.7319x
R² = 0.9961
74.531
64.033
40.471
Shear Stress in Kpa
Normal Stress in Kpa
0
20
40
60
80
100
0
50
100
150


b
Shear Stress VS Normal Stress 20% tire by weight of sand for 50mm tire shred
y = 0.7174x + 3.7057
R² = 0.9981
81.41
60.663
42.798
Shear Stress in KPa
Normal Stress in KPa
0
20
40
60
80
100
0
50
100
150


c
Shear Stress VS Normal Stress 20% tire by weight of sand for 75mm tire shred
y = 0.8631x
R² = 0.997
94.834
50.453
64.439
Shear Stress in KPa
Normal Stress in KPa
0
20
40
60
80
100
0
20
40
60
80
100
120


d
Shear Stress VS Normal Stress 20% tire by weight of sand for 100mm tire shred
y = 0.9109x
R² = 0.9883
106.437
49.753
61.876
Shear Stress in KPa
Normal Stress in KPa
0
20
40
60
80
100
120
0
20
40
60
80
100
120


e
Shear Stress VS Normal Stress 30% tire by weight of sand for 75mm tire shred
y = 0.9112x
R² = 0.9959
102.315
66.529
51.124
Shear Stress in KPa
Normal Stress In Kpa
0
20
40
60
80
100
120
0
20
40
60
80
100
120


f
Shear Stress VS Normal Stress 20% tire by weight of sand for 100mm tire shred
y = 0.9109x
R² = 0.9883
106.437
49.753
61.876
Shear Stress in Kpa
Normal Stress in KPa
0
20
40
60
80
100
120
0
20
40
60
80
100
120

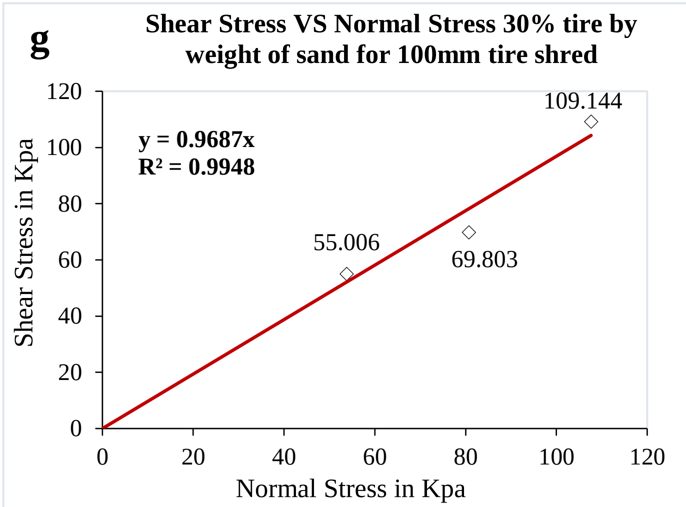


Figure 3: *Shear stress vs normal stress graphs for 50, 75 and 100mm tire sizes at 20% and 30% tire by weight of sand.*

Table 3*-Tests results*

Size of TDA (mm)	Percentage of TDA (%)	Normal load (kN)	Shear Stress (kPa)	Friction Angle
Sand	0	20	40.47	
		30	64.03	32
		40	74.53	
50	20	20	42.8	
		30	60.66	36
		40	81.41	
50	30	20	46.09	
		30	57.78	39
		40	89.63	
75	20	20	50.45	
		30	64.44	40
		40	94.83	
75	30	20	51.12	
		30	66.53	43
		40	102.32	
100	20	20	49.75	
		30	61.88	46
		40	106.44	
100	30	20	55.01	
		30	69.8	44
		40	109.14	

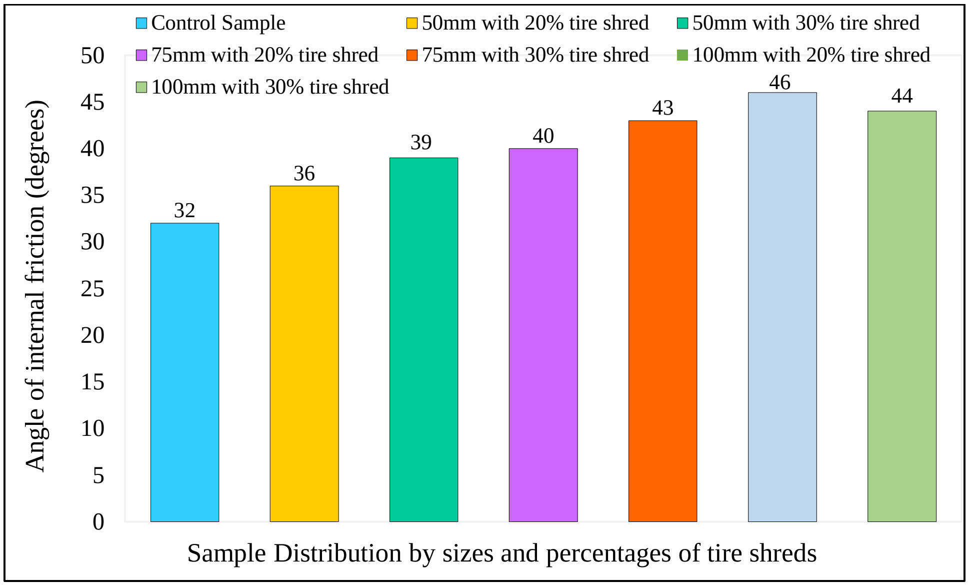


Figure 4:Variation of angle of internal friction with coresponding percentages and sizes of tire shreds."

4 Conclusion

This study was aimed to investigate the shear strength properties of sand mixed with varying proportions of tire shreds. The shear strength properties of sand tire mix containing various sizes of tire-shreds (i.e., 50mm, 75mm, and 100mm) were evaluated. The following points summarize the main conclusions of the study.

i. It was concluded that the shear strength of sand mixed with tire shred of different sizes increases with an increase in the size of tire shred up to a certain limit beyond which it starts to decrease. It was found that the maximum shear strength is attained at 100mm tire shred size with a mixing ratio of 20% tire-shred and 80% sand as compared to pure sand alone. At that mixing ratio, maximum shear strength of 106kPa with friction angle of 46˚ was obtained as compared to pure sand without tire shred containing shear strength 75kPa with a friction angle of 32˚.

ii. The optimum values of mixing ratio containing 20% tire shred and 80% sand were obtained at 100mm size of tire shred

iii. A substitution of scrap tire shreds as an aggregate up to 20% can be utilized with a maximum size of 100mm with reasonable shear strength.

Acknowledgement

"The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged."

References

1. Attom, M.F., *The use of shredded waste tires to improve the geotechnical engineering properties of sands.* Environmental Geology, 2006. **49**(4): p. 497-503.
2. Edinçliler, A. and V. Ayhan, *Influence of tire fiber inclusions on shear strength of sand.* Geosynthetics International, 2010. **17**(4): p. 183-192.
3. Neaz Sheikh, M., et al., *Shear and compressibility behavior of sand–tire crumb mixtures.* Journal of Materials in Civil Engineering, 2013. **25**(10): p. 1366-1374.

4. Anbazhagan, P. and D. Manohar, *Energy absorption capacity and shear strength characteristics of waste tire crumbs and sand mixtures.* International Journal of Geotechnical Earthquake Engineering (IJGEE), 2015. **6**(1): p. 28-49.
5. Anbazhagan, P., D. Manohar, and D. Rohit, *Influence of size of granulated rubber and tyre chips on the shear strength characteristics of sand–rubber mix.* Geomechanics and Geoengineering, 2017. **12**(4): p. 266-278.
6. Mohamad, E.T., et al., *Effects of relative density on shear strength characteristics of sand-tire chips mixture.* Electronic Journal of Geotechnical Engineering, 2013. **18**(4): p. 623-632.
7. Anwar, M. and F. Ahmad, *Optimum Values for Mixing Ratio and Tire Shred Size of Sand Tire Mix*. 2020.
8. Ghazavi, M., *Shear strength characteristics of sand-mixed with granular rubber.* Geotechnical & Geological Engineering, 2004. **22**(3): p. 401-416.
9. Yoon, Y., S. Cho, and K. Kim, *Engineering properties of tire treads for soil reinforcement.* Journal of the Korean Geoenvironmental Society, 2007. **8**(1): p. 49-55.
10. Bernal, A., et al., *Interaction between tire shreds, rubber-sand and geosynthetics.* Geosynthetics International, 1997. **4**(6): p. 623-643.
11. Humphrey, D.N. and W.P. Manion. *Properties of tire chips for lightweight fill*. in *Grouting, soil improvement and geosynthetics*. 1992. ASCE.
12. Ahmed, I., *Laboratory study on properties of rubber-soils.* 1993.
13. Edil, T.B. and P.J. Bosscher, *Development of engineering criteria for shredded waste tires in highway applications*. 1992: Wisconsin Department of Transportation, Division of Highways, Bureau of ….
14. Bali Reddy, S., D. Pradeep Kumar, and A. Murali Krishna, *Evaluation of the optimum mixing ratio of a sand-tire chips mixture for geoengineering applications.* Journal of Materials in Civil Engineering, 2016. **28**(2): p. 06015007.
15. Al-Rkaby, A.H., *Strength and Deformation of Sand-Tire Rubber Mixtures (STRM): An Experimental Study.* Studia Geotechnica et Mechanica, 2019. **41**(2).
16. Soil, A.C.D.-o. and Rock, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) 1*. 2017: ASTM International.