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Characterization of embankment material using sand tire mix as additive and validating the results obtained from large scale direct shear test in Abaqus software

Anwar Muhammad * and Rawid Khan

Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan.

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Abstract

Laboratory direct shear tests often overlook larger particles due to limitations in shear box design, resulting in an inadequate portrayal of real-world soil conditions. To address this gap, the use of large-scale direct shear apparatus capable of accommodating larger particles is essential. However, conducting such tests with varied sizes of tire shreds, mixing ratios, and loads is intricate and resource-intensive. Therefore, the utilization of numerical modeling is suggested to simulate sand-tire mixtures under diverse conditions. This study presents conclusions derived from comparing numerical results with experimental observations, demonstrating a close correspondence between the two. It offers a comprehensive examination of the impact of sand and shredded tires mixtures on shear strength, indicating a consistent pattern: increased quantities of tire shreds correspond to heightened friction angles. Furthermore, specimens containing larger shredded tire particles display elevated friction angles, implying a possible connection between particle size and frictional behavior. This investigation underscores the importance of numerical modeling as a cost-efficient and effective approach to complement experimental inquiries, enriching our comprehension of soil-tire mixture dynamics and guiding practical applications in transportation and geotechnical engineering.

Keywords: Sand Tire Mix; Frictional Angel; Shear Strength; Abaqus Software; Tire shred; Normal and Shear Stress.TDA

1. Introduction

Around 13.5 million tons of scrap tires are disposed of annually worldwide, which poses fire and health risks when burned or stacked. To tackle these challenges, tires are shredded and recycled as backfill material for various structures such as retaining walls and bridge abutments. This method offers an environmentally friendly solution to tire waste while enhancing infrastructure. The shredded tires, known as Tire Derived Aggregate (TDA), have a lightweight nature with a density typically ranging from 560 to 1040 kg/m^3. Due to their low density, they exert less lateral earth pressure on structures and improve drainage during construction. These unique characteristics make tire shreds ideal for filling retaining walls or embankments. Moreover, they are cost-effective, with prices ranging from $5 to $50 per cubic yard, depending on the grade. Compared to other lightweight fill materials, tire shreds are relatively affordable. Therefore, incorporating them into soil with low shear strength not only addresses environmental concerns but also resolves transportation and geotechnical issues faced by Civil Engineers. In of road construction, this material serves multiple functions, such as being a lightweight option for embankment fill, a layer for frost insulation, and a component for drainage. However, its notable drawback lies in its high compressibility, requiring a thicker superstructure to counteract this quality. To address this issue, reinforcements like steel nets are utilized to minimize deflections on the road surface. Moreover, in landfill design, tire shred material proves to be a well-suited choice for drainage purposes, particularly in final covers where its excellent drainage capabilities come into play. Various studies have explored the shear strength properties of sand-rubber mixtures, indicating that adding a specific amount of tire shred to sand

* Corresponding author: Muhammad Anwar.

enhances shear strength behavior. However, the effectiveness of this enhancement depends on various factors such as Normal stress, TDA mixing ratio, tire aspect ratio, tire shred length, sand matrix unit weight, and the compaction process.

1.1. Large scale test using tired shreds

Ahmed and Marto [1] conducted extensive research demonstrating that the inclusion of tire shreds effectively reinforces sand. Their findings, , illustrate a notable increase in the shear strength of sand with the addition of tire shreds, primarily due to the enhancement of the friction angle "C". However, it is crucial to maintain an optimal mixing ratio of Tire Derived Aggregate (TDA) with sand to prevent segregation issues. They conducted analyses on the stress-strain behavior of sand-tire mixtures, incorporating varying percentages of tire shreds ranging from 0% to 100%,[2] Hamza Amin et al., had investigated the effects of adding tire chips to sand and its implications on shear behavior as evaluated through Direct Shear and Triaxial Apparatus tests. The experiment involved four specimens: pure sand and sand mixtures containing 20%, 30%, and 40% tire chips. To ensure consistency in stress levels, varying confining pressures of 50, 100, and 150 kPa were applied alongside normal stress. The Direct Shear Apparatus, characterized by a circular shape with an area of 16.62 cm^2, and the Triaxial Shear Apparatus, with dimensions of 7.2 cm in height and 3.2 cm in diameter, were employed to assess stress-strain behaviors under ordinary loading and deviatoric stress conditions. Results from the study indicated that the sand mixture with 30% tire chips exhibited optimal shear properties in both the direct shear and triaxial shear tests. Measurements of angles of internal friction (Φ') and cohesion (c') were taken for specimens with and without tire chips, revealing improvements in the shear strength parameters with the inclusion of tire chips. Li, W., Kwok, C. Y., Sandeep, C. S., & Senetakis [3]conducted a study focusing on Drained Triaxial shear tests to analyze the strength characteristics of well-graded sand, specifically completely decomposed granite (CDG), both independently and in mixtures with Tire Derived Aggregate (TDA). The research aimed to understand how the strength properties of sand and TDA are influenced under specific conditions. The study involved the utilization of three different chip sizes: GR1 (0.3-0.6 mm), GR2 (1.18-2.36 mm), and GR3 (2.36-5 mm), combined with completely decomposed granite, while varying the rubber content from 0% to 30%.

Their findings revealed that the strength of CDG-GR1 mixtures decreased with an increase in rubber content. In contrast, the strength of CDG-GR2 and CDG-GR3 mixtures exhibited a significant increase with higher rubber content, with strength decreasing only at 10%.

The lab results from Hüseyin Suha AKSOY* [4] showed that when you mix 20% tire shreds and 80% sand, and the tire shreds are 50mm in size with a moisture content of 8.46%, you can achieve a maximum dry density of 21.446KN/m3. This is much higher than the maximum dry densities you get when you use 75mm and 100mm tire shreds with the same 20/80 mixing ratio, which are 19.75KN/m3 and 17.811KN/m3, respectively.

2. Materials and Methods

The shear strength behavior (frictional angel) of sand tire mix structure will be simulated using the Finite Element Method (FEM) in ABAQUS software. The experimental results obtained from large-scale direct shear test apparatus will be compared with the data in the form of Normal Stress, Shear Stress, and Displacement Time Graphs will be validated with that in ABAQUS .After the confirmation of the results, a comparative study will be conducted to ascertain the impact of various tire characteristics and loading scenarios on the Shear strength parameter, specifically the Cohesion and Friction angle of the sand tire mix.

In the large-scale direct shear apparatus, the working principle is same as that of the standard direct shear instrument. However, the shear box size was notably larger compared to the standard size specified by ASTM D 3080-90 (2011). The dimensions of the shear box were strictly controlled by ASTM specifications. Consequently, the test necessitated large capacity loading devices to apply both the normal load and lateral shearing loading on the sample during the test process. The direct shear apparatus comprised two shear boxes, three steel girders, a displacement transducer, a load cell, a hydraulic jack/actuator, and a concrete block housing all components. The shear box dimensions were (2.x2x1) ft^3, with the upper box fixed and the lower box movable for shearing over the upper one. The displacement transducer measured shear deformation, while the load cell gauged shear load applied on the sample. A data logger unit recorded shear data throughout the testing process.

2.1. Tire Derived Aggregate

Tire shred sizes typically ranged from to 2 inches, 3 inches, and 4 inches. Whole tires or parts of scrap tires were shredded by shredders equipped with knives or blades. Usually, multiple passes through a shredder were necessary to achieve tire shred sizes less than 300 mm. Producing smaller sizes of tire shreds was more expensive. Hence, larger-size tire shreds were more economical for use as construction materials. Nonetheless, the engineering properties of the tire shred-sand mixtures and the potential construction difficulties in the field also needed to be considered during the selection process of the tire-shred size to be used.

Figure 1 Derived Aggregate

2.2. Optimum Size of Tire Shreds

Whole tires or parts of scrap tires were shredded by shredders equipped with knives or blades. Usually, multiple passes through a shredder were required to achieve tire shred sizes less than 300 mm. Producing smaller sizes of tire shreds was more expensive. Consequently, larger-size tire shreds were considered more economical when intended for use as construction materials. The average lengths, widths, and thicknesses for these size ranges of 50-100 mm is 76 mm, 49 mm, and 10 mm. Typically, the length of the tire shreds is greater than their width, which in turn is greater than their thickness. Thus, tire shreds have a shape that is elongated and flat. An important property indicative of the shape of tire shreds is the aspect ratio, defined as the length-to-width ratio. The average aspect ratios (length/width) are 1.6 for 2”,3”and 4”- long tire shreds.

Figure 2 Tire Derived Aggregate

2.3. Determination of maximum dry density

In the study, a series of compaction tests was conducted to ascertain the optimal mixing ratio of tire shred-sand mixtures. Various mixing ratios (20%, 30%, tire by weight of sand) were tested using shredded tires of three different sizes (2 inches, 3 inches, 4 inches nominal size) along with sand. Employing the standard Proctor compaction effort (2700 kN-m/m3), the highest dry density was achieved in sand, followed by the 2-inch, 3-inch, and 4-inch tire sizes, respectively. A graph illustrating the relationship between maximum dry density and optimum moisture content is presented below.

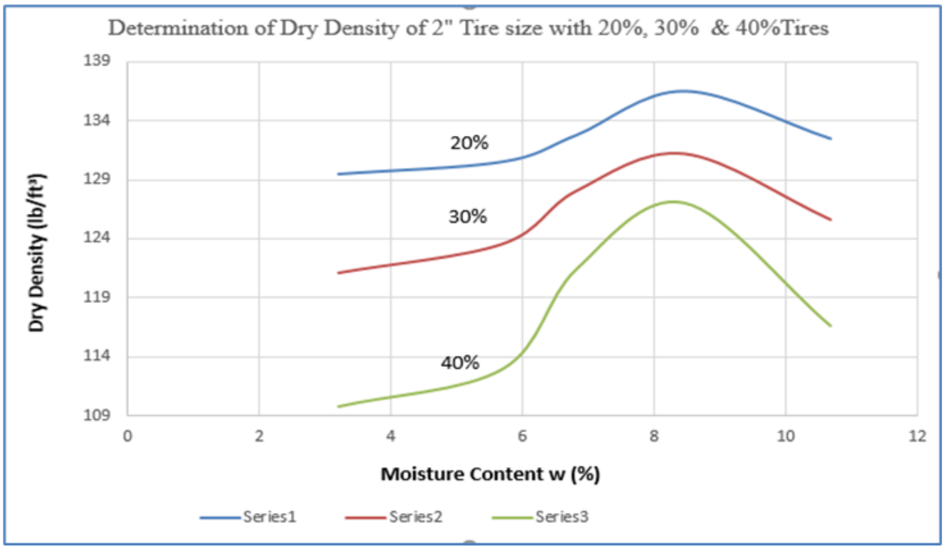

Figure 3 Graph of dry density and OMC of 2-inch tire size with different percentage

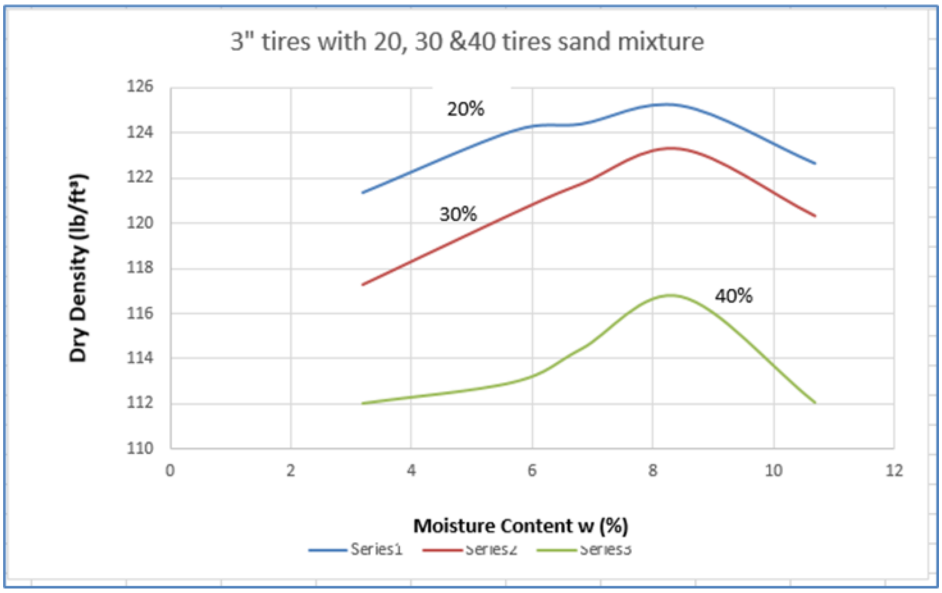

Figure 4 Graph of dry density and OMC of 3-inch tire size with different percentage

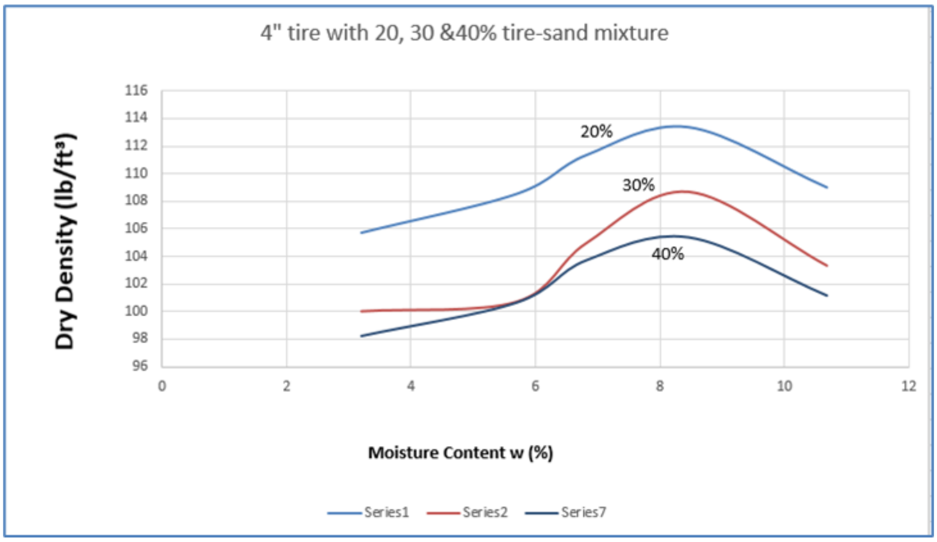

Figure 5 Graph of dry density and OMC of 4-inch tire size with different percentage

3. Results

The results from experiment and Abaqus software are as follow.

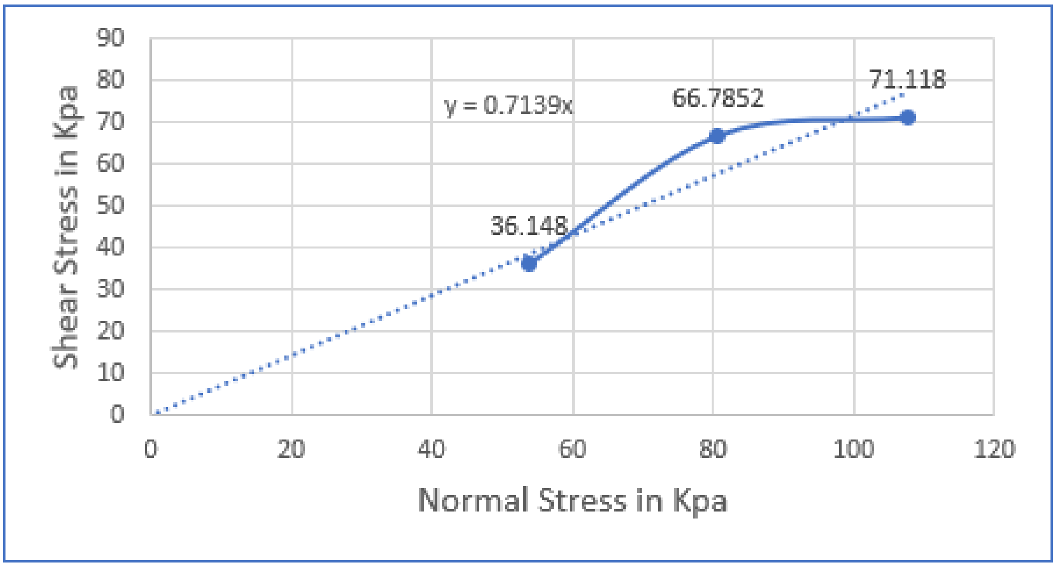

Figure 6 Shear Stress VS Normal Stress graph for sand only

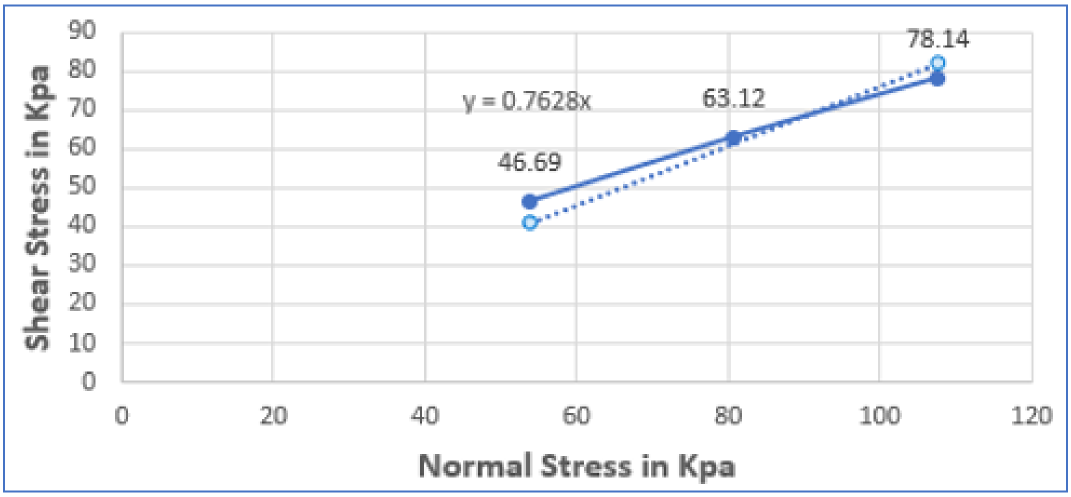

Figure 7 Shear Stress VS Normal Stress 20% tire by weight of sand for 2-inch tire shred

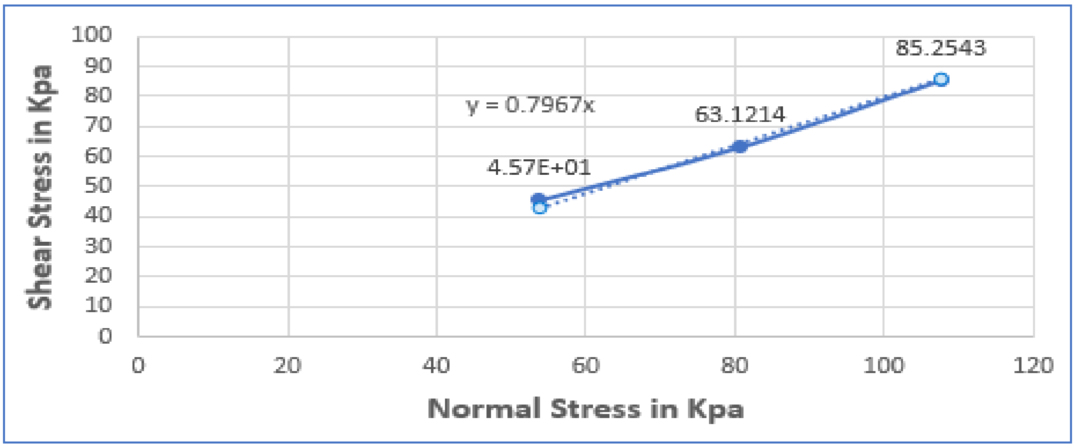

Figure 8 Shear Stress VS Normal Stress 30% tire by weight of sand for 2-inch tire shred

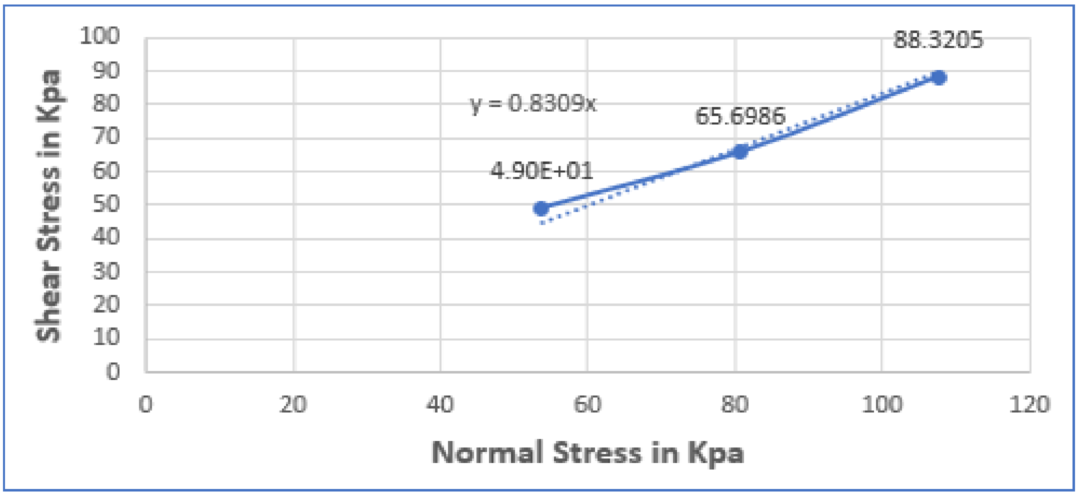

Figure 9 Shear Stress VS Normal Stress 20% tire by weight of sand for 3-inch tire shred

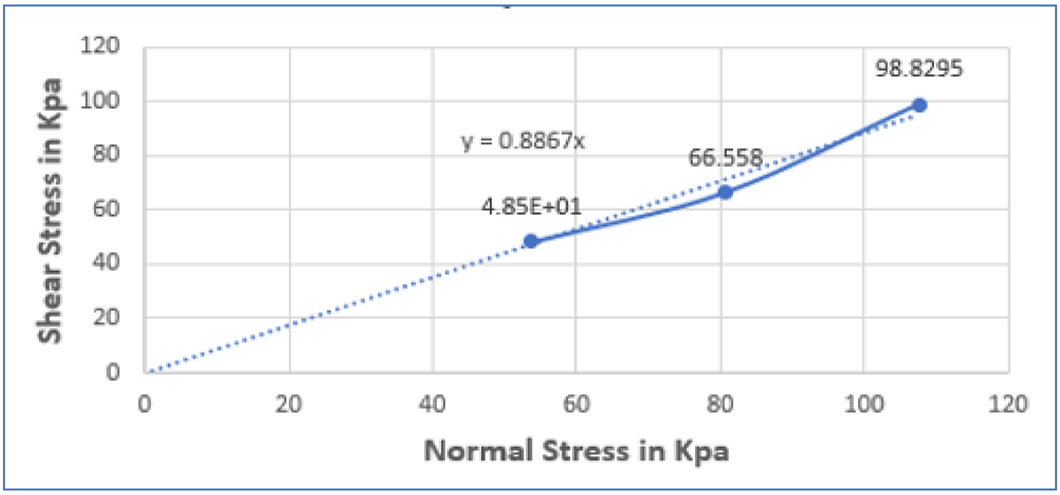

Figure 10 Shear Stress VS Normal Stress 30% tire by weight of sand for 3-inch tire shred

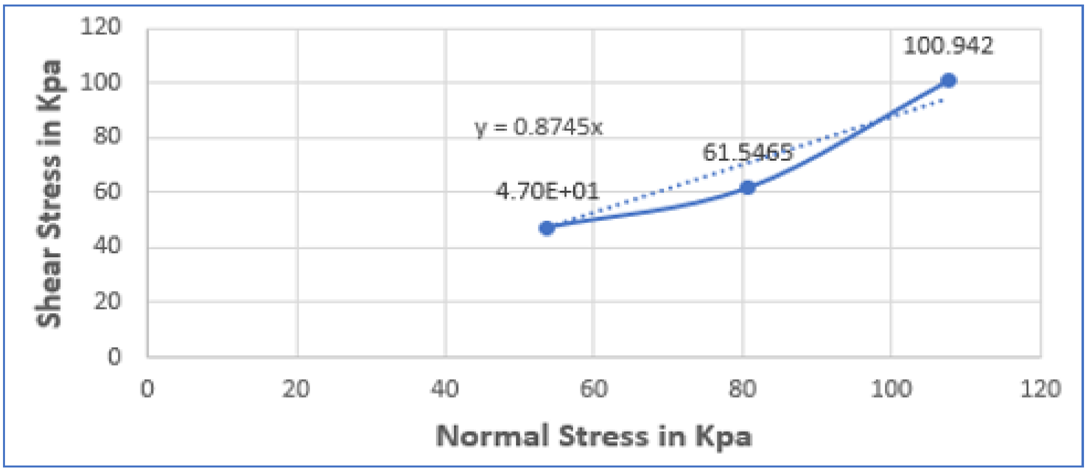

Figure 11 Shear Stress VS Normal Stress 20% tire by weight of sand for 4-inch tire shred

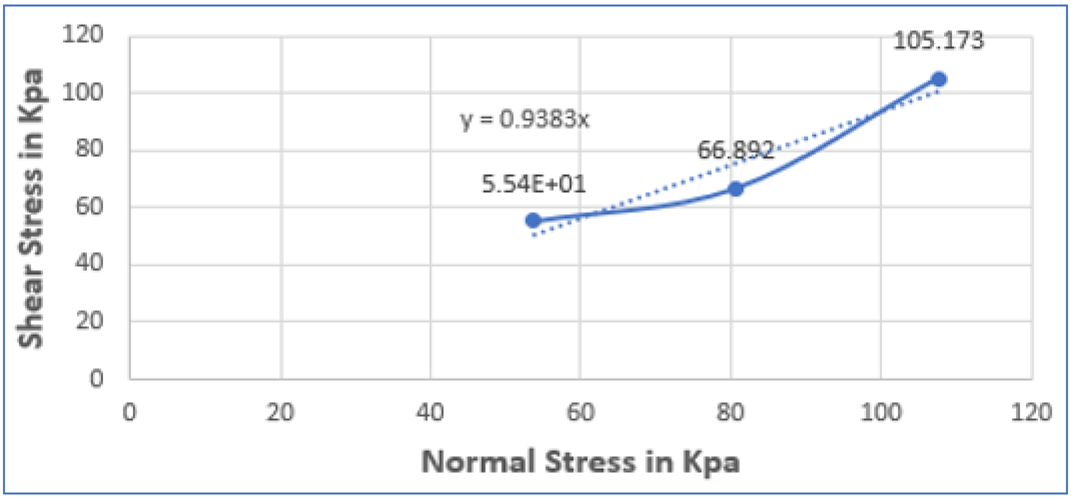

Figure 12 Shear Stress VS Normal Stress 30% tire by weight of sand for 4-inch tire shred

Table 1 Comparison between Abaqus and Experimental Value for Frictional Angle

Size of TDA (inches)	Percentage of TDA (%)	Friction Angle from Abaqus	Friction Angle from Experiment	Difference
Sand	0	35.28	36.38	1.10
2	20	37.34	35.65	1.69
2	30	38.21	39.20	0.99
3	20	39.72	40.23	0.51
3	30	41.54	43.56	2.02
4	20	42.31	44.03	1.72
4	30	43.16	45.17	2.01

4. Discussions

The goal of this study was to demonstrate how different sizes of shredded tires affect the strength of sand mixes in order to learn more about the impact of particle size variation. The findings for model 1 indicate the link between maximum shear stress and normal stress. The trend line equation has been calculated, yielding an angle of friction of 35.28 degrees. In model 2, the angle of friction is 37.336 degrees, whereas the experimental finding was 35.65 degrees. However, when Model 1 is examined, it reveals a greater friction value.

This low friction value hints at the fundamental impact of rubber tire shreds on friction The angle of friction in model 3 is calculated to be 38.21 degrees, although the experimental measurement revealed a nearly identical result of 39.20 degrees. In model 4, the estimated angle of friction is 39.72 degrees, which nearly matches the actual result of 40.23 degrees. Model 5's angle of friction is 41.54 degrees, which nearly matches the experimental result of 43.56 degrees. This agreement reflects a strong model. In model 6, the angle of friction is computed as 42.31 degrees similar to the experimental reading of 44.03 degrees. This alignment indicates a dependable model. However, the prior model showed a larger friction value, showing that rubber tire shreds had a major impact. Model 7's angle of friction is 43.16 degrees, which is quite close to the experimental result of 45.17 degrees. This indicates a dependable model. Furthermore, the prior model showed a greater friction value, suggesting the presence of rubber tire shreds.

5. Conclusion

The findings of the research are as follows:

- There was a close match between experimental observations and numerical results.
- A thorough summary of the numerical results from model testing on the impact of shredded tires and sand mixes on shear strength.
- A consistent pattern has been observed: a higher friction angle is caused by more tires that are shredded to the ideal quantity. Segregation causes the dry density to drop below the optimal value.
- Higher friction angles are seen in samples containing larger pieces of shredded tire, which may indicate a relationship between frictional behavior and particle size.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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