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Characteristics of Sand-Waste Tyre Rubber Composite as Backfill Material

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ABSTRACT

Waste tyre rubber offers an alternative to natural sand as a backfill material, potentially reducing the dependency on natural sand usage in construction. The purpose of this study is to investigate the properties of waste rubber as a potential backfill material for retaining walls and to assess the shear strength characteristics of the sand-rubber composite when used as a backfill for retaining walls, ultimately identifying the optimal sand-rubber composite ratio for effective backfill application. This study employed sieve analysis and specific gravity testing to identify the physical attributes of waste tyre rubber. Subsequently, direct shear box tests were conducted utilizing ratios of 100%, 50%, 75%, and 25%. Two types of rubber were utilized in this study Granulated Rubber (GR) with particle sizes ranging from 1 to 5 mm, and Mulch (MR) with particle sizes exceeding 25 mm. The findings reveal that the Cu value for waste rubber is less than 2.50 and the Gs value is less than 1.5, indicating favourable characteristics. Moreover, the 25% GR and MR compositions exhibit the highest shear stress values at 0.0347 N/m^2 and 0.0296 N/m^2, respectively. In conclusion, it has been determined that the optimal proportion of waste rubber for the application of the sand-waste tyre rubber composite as a backfill material is 25%.

Keywords:
Backfill; waste rubber tyre; sand-rubber; shear stress; direct shear

1. Introduction

Backfill construction is crucial for maintaining structural integrity, stability, and overall performance, particularly in the context of retaining walls [1]. The integration of waste tyres as backfill material has been shown to yield significant improvements in shear strength and permeability, as demonstrated in recent reviews [2]. This sustainable approach not only addresses

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issues related to lateral thrust and displacement in retaining walls but also simplifies design complexities and dimensions, resulting in a more economically viable structure [2].

Conventionally, natural sand has been widely employed as the primary backfill material in projects involving retaining wall construction. Nevertheless, the increasing emphasis on adopting sustainable practices and the motivation to mitigate environmental impact have ignited a burgeoning interest in investigating alternative construction materials [3,4]. This approach aligns with the pursuit of the United Nations Sustainable Development Goals, particularly those focused on innovation in infrastructure.

Waste tyre rubber does not readily decompose under natural conditions, leading to its accumulation becoming breeding grounds for mosquitoes and disease-carrying insects, resulting in air and water pollution [5,6]. Given the significant volume of used tires disposed of annually, several studies have been conducted to explore the properties of waste rubber as a substitute for natural sand in backfill applications. This innovation serves as an alternative solution for backfill material, reducing reliance on natural sand.

Figure 1 below provides an illustration of the waste tyre rubber production process. Due to its lightweight nature, rubber holds the potential to decrease costs and material consumption. Additionally, it promotes environmentally friendly and ecologically sound construction practices [7]. The substitution of sand with rubber can yield significant and positive outcomes in terms of retaining wall efficiency. Ensuring proper backfilling is also essential to maintaining stability and supporting applied loads.

Fig. 1. Waste rubber production process [8]

In distinguishing itself from previous studies that predominantly focused on granular waste rubber [9-11], this study aims to assess the shear strength characteristics of the sand-rubber composite in various ratios, including 100%, 50%, 75%, and 25% waste tire rubber. This unique focus on different particle sizes and ratios contributes novel insights into the potential applications of waste tire rubber in backfilling for retaining walls.

2. Methodology
2.1 Sieve Analysis Test

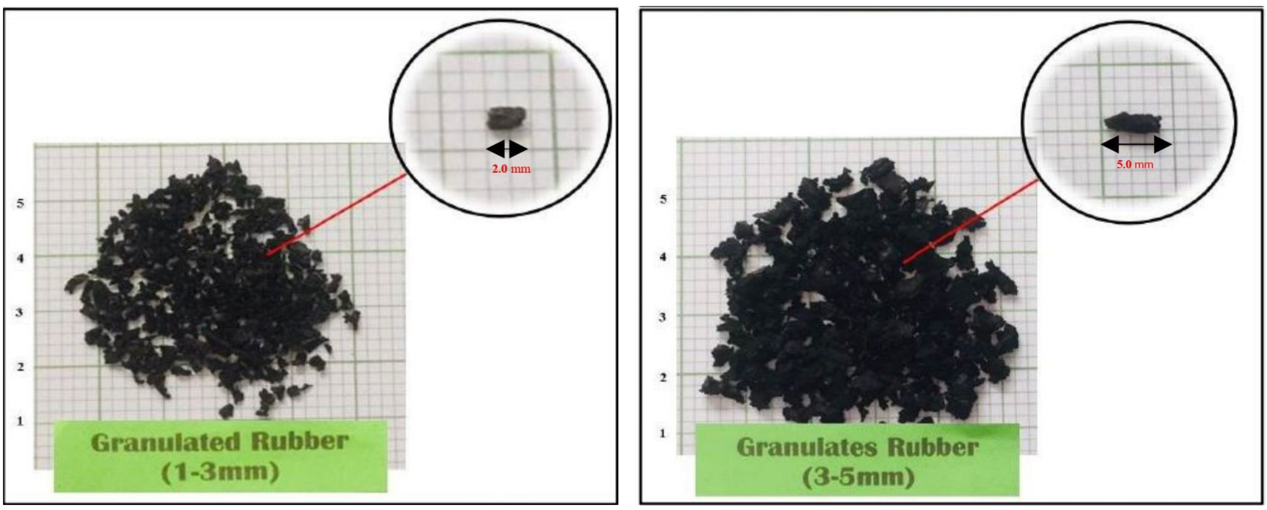
The size distribution of the samples was determined through mechanical sieving. The test was carried out following the guidelines outlined in the BS 1377-Part 2 standard [12], which outlines the procedures for classifying and identifying the fundamental physical characteristics of the samples. The machine employed for the sieving process was a motorized sieve. Within a standard sieve shaker, particles are effectively separated by agitating the sample as it traverses a series of chambers with mesh filters. In order to prepare the sand, it underwent a drying process in an oven for 24 hours at a temperature of 108°C. The weight of the samples used for conducting this analysis was 250 grams.

The main materials used are sand and waste rubber that have been processed according to size as shown in Table 1. Specifically, the sand utilized in these tests passes through a 2 mm sieve, while the granular waste rubber (GR) passes within the range of 1 to 5 mm, and the mulch rubber (GR) is less than 26 mm.

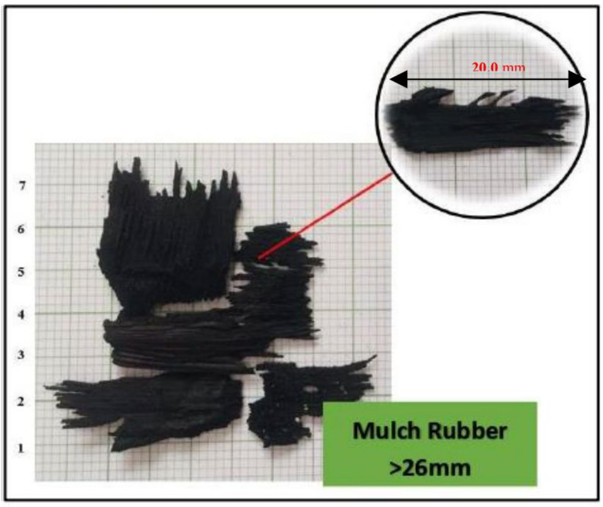
Table 1
Size of materials sand-waste rubber

Materials Name	Particle Size
Sand (S)	Passing Sieve 2mm
Granulated Rubber (GR1)	1-3mm
Granulated Rubber (GR2)	3-5mm
Mulch Rubber (MR)	≥ 26 mm

Figure 2 below provides a comprehensive overview of each variety of waste rubber employed in accordance with their respective sizes.



(a) (b)



(c)

Fig. 2. Types of rubber used for testing (a) granulated rubber (gr1); size 1-3 mm (b) granulated rubber (gr2); size 3-5 mm (c) mulch rubber (mr); size ≥ 26 mm

2.2 Specific Gravity

The specific gravity serves to determine the ratio between the unit masses of rubber and sand. A standard gas jar equipped with stoppers, as depicted in Figure 3, is utilized for establishing a set of specific gravity values. After ensuring the jar's surface is dry, the weight of the stopper, rubber or sand, and water is calculated. Subsequently, the jar is emptied, filled with desired water, and dried, with the mass of the stopper, jar, and water all measured.

In accordance with the guidelines of BS 1377 - Part 2 standard [12], for medium-grained soil, each specimen should ideally weigh between 5 to 10 g; hence, the weight of both sand and rubber specimens was set at 10 g. For the preparation of these specimens, it is imperative that the sand and waste rubber materials are finer than 2 mm.

Fig. 3. Apparatus for specific gravity

2.3 Direct Shear Box Test

The direct shear box test is utilized to ascertain the shear strength of the sand-waste rubber composite. This test employs a shear box measuring 60 mm (width) × 60 mm (length) × 20 mm (height), conforming to the specimen size guidelines specified in BS 1377-4: 1990 [13], as depicted in Figure 4.

Initially, the sand and waste rubber mixtures, designated as GR, were introduced into the shear box by exerting pressure on the upper grid plate. Subsequently, a tamper was employed to densely pack the sample within the direct shear box. Following this, the shear box was positioned within the direct shear machine.

The horizontal shear displacement rate was established at 0.5 mm/min, accompanied by three distinct applied loads: 0 g, 250 g, and 750 g. The testing encompassed sand, and GR samples with varying percentage ratios of 0%, 25%, 50%, 75%, and 100%, all subjected to different normal stresses of 0 N/m², 0.7 N/m², and 2.0 N/m².

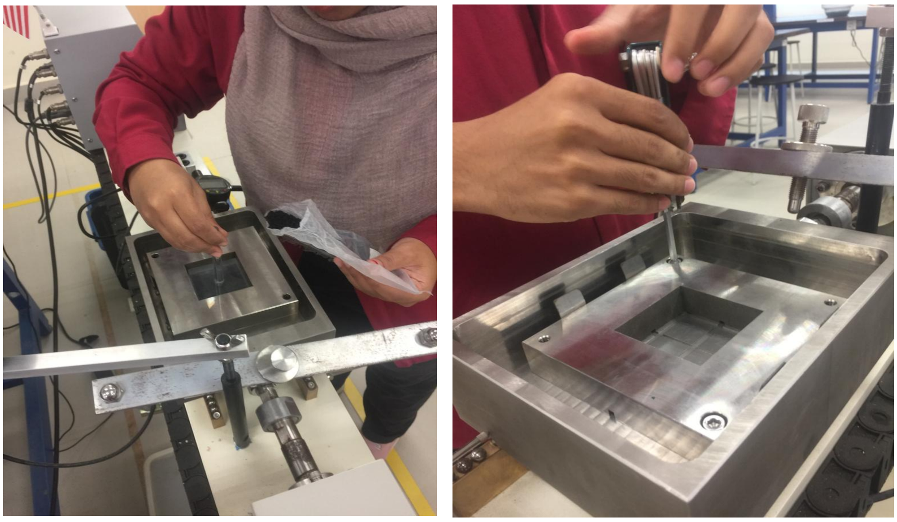


Fig. 4. Sample preparation into direct shear test machine

3. Results

3.1 Sieve Analysis

The particle size distribution of the sand and waste rubber (GR and MR) is depicted in Figure 5 below. As indicated by the sieve graph in Figure 5, the particle sizes of waste rubber GR and MR align with the particle size distribution of sand, falling within the range of 0.10 mm to 3 mm. The distribution pattern of GR bears a resemblance to that of sand due to the relatively similar shapes of GR and sand particles.

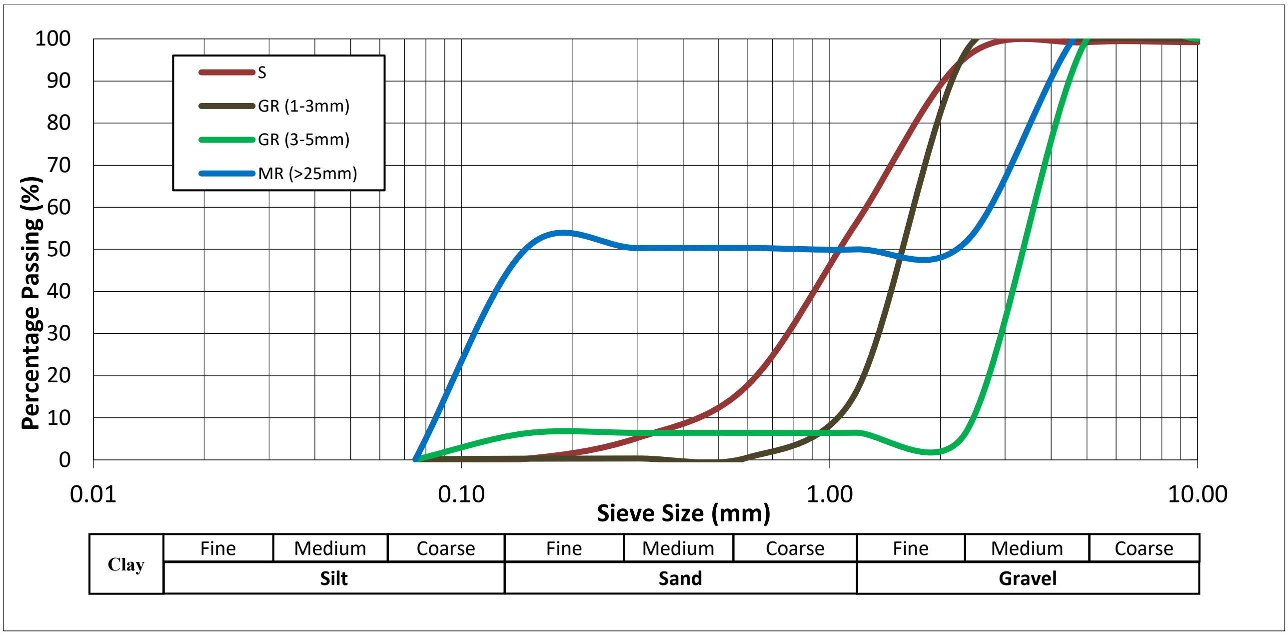


Fig. 5. Particle size distribution of the sand and waste rubber (GR and MR)

The uniformity coefficient (Cu) and curvature coefficient (Cc) values for both sand and waste rubber (GR and MR) are provided in Table 2. In relation to Table 2, it's worth noting that the uniformity coefficient (Cu) for waste rubber GR is lower than the sand value of 3.17, particularly for particle sizes less than 5 mm. This observation aligns with the findings presented in reference [8], wherein the Cu value for particle sizes below 7 mm is reported to be below 2.50.

Additionally, according to references [14] and [15], it was concluded that a higher ratio of curvature coefficient to uniformity coefficient (Cc/Cu) results in lower cohesion and internal angle of friction, and the larger the particle size, the higher the internal angle of friction. In contrast, the sand has no cohesion and hardly become denser.

Table 2
Summary of Uniformity Coefficient (Cu) and Curvature Coefficient (Cc)

	Uniformity Coefficient (Cu)	Curvature Coefficient (Cc)	Cc/Cu
Sand (S)	3.17	0.19	0.06
Granulated Rubber (GR 1: 1-3 mm)	1.91	1.00	0.52
Granulated Rubber (GR 2: 3-5 mm)	1.58	5.76	3.64
Mulch Rubber (MR)	3.44	0.97	0.28

3.2 Specific Gravity

The analysis of specific gravity data for sand and waste rubber (GR and MR) is presented in Table 3. According to the results, it has been determined that the specific gravity of granulated rubber (GR) with particle sizes ranging from 1 to 3 mm is 0.58, granulated rubber (GR 2) with particle sizes between 3 to 5 mm is 0.70, and mulch rubber (MR) has a value of 1.02.

In summary, it can be concluded that the specific gravity of waste rubber is lower than that of sand, which is 2.62. Moreover, it falls within the suitable range for waste rubber, which is the specific gravity value less than 1.5 as indicated by references [16,17].

Table 3
Specific Gravity of Sand and Waste Rubber (GR and MR)

	Specific Gravity (G_s)
Sand (S)	2.62
Granulated Rubber (GR 1: 1-3 mm)	0.58
Granulated Rubber (GR 2: 3-5 mm)	0.70
Mulch Rubber (MR)	1.02

3.3 Relationship Shear Stress and Sand-Waste Tyre Rubber

Based on Figures 6 and Figure 7, the combination of 75%S and 25%GR in both the dry and wet samples yields the highest shear stress values, measuring 0.0236 N/m^2, 0.0261 N/m^2, and 0.0354 N/m^2 for the dry condition. Conversely, for the wet sample, the maximum shear stress values are 0.0091 N/m^2, 0.0231 N/m^2, and 0.039 N/m^2.

Furthermore, the dry sample with 100%GR has the lowest shear stress value, with readings of 0.0217 N/m^2, 0.0226 N/m^2, and 0.0243 kN/m^2. Meanwhile, the wet sample containing 50%S and 50%GR exhibits the lowest values, measuring 0.0126 N/m^2, 0.0227 N/m^2, and 0.0184 N/m^2.

It can be concluded that the ideal ratio for sand and GR is 75% S and 25% GR which contributes to the optimum shear strength value to achieving the highest shear stress value.

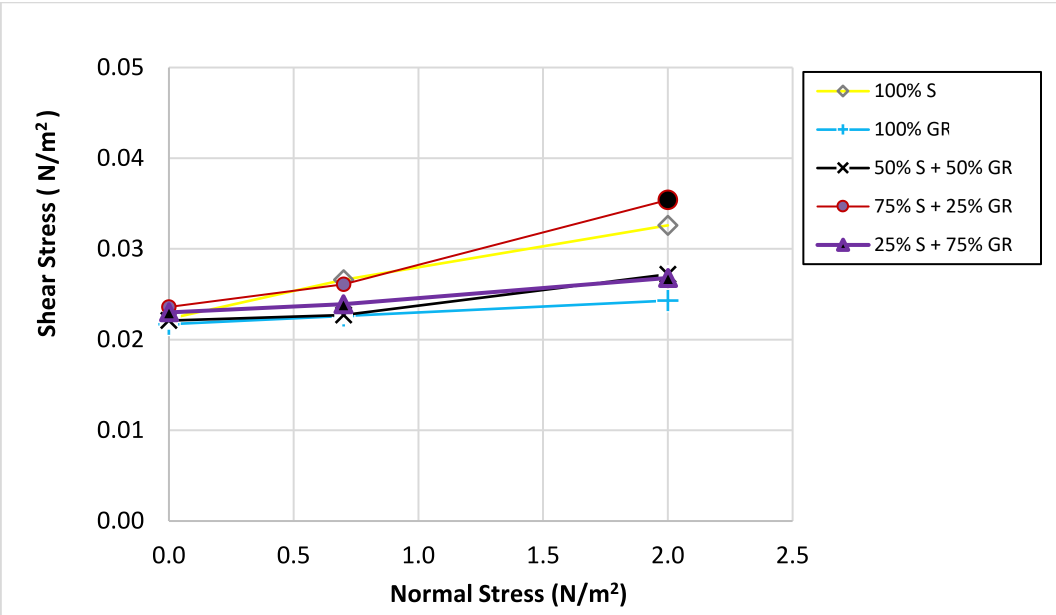


Fig. 6. Graph normal stress versus shear stress for GR (dry sample)

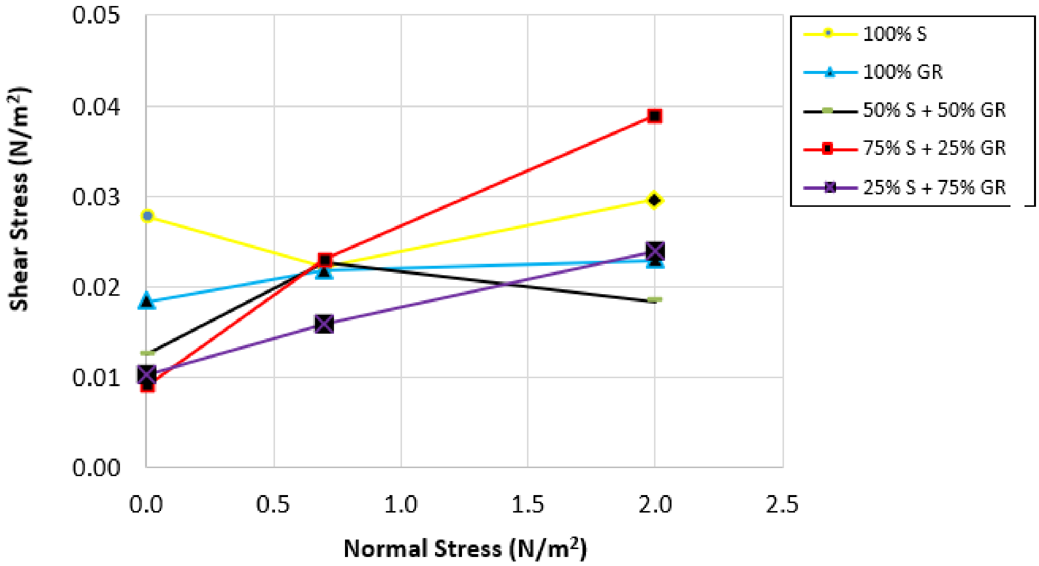


Fig. 7. Graph normal stress versus shear stress for GR (wet sample)

Furthermore, Figures 8 and Figure 9 depict the shear stress values of MR under both dry and wet conditions. As observed in the figures, the combination of 75% S and 25% MR yields the highest shear stress values, measuring 0.021 N/m², 0.0226 N/m², and 0.0347 N/m² for the dry sample, and 0.0203 N/m², 0.0302 N/m², and 0.0336 N/m² for the wet sample.

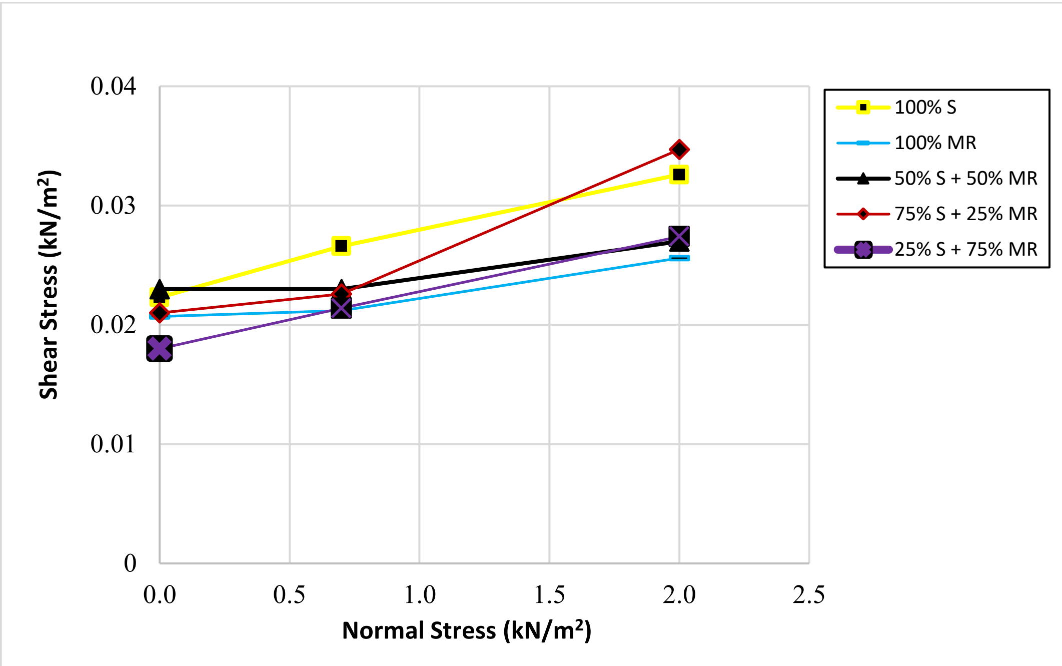


Fig. 8. Graph normal stress versus shear stress for MR (dry sample)

Moreover, when considering the MR sample composed entirely of MR (100%) in dry conditions, it registers the lowest shear stress values within the MR group, measuring 0.0207 N/m², 0.0212 N/m², and 0.0256 N/m². Conversely, the wet samples with a composition of 25% S and 75% MR exhibit the lowest values, quantified at 0.0163 N/m², 0.0301 N/m², and 0.0296 N/m², respectively. It can be concluded that the ideal ratio for sand and MR is 75% S and 25% MR which contributes to the optimum shear stress value.

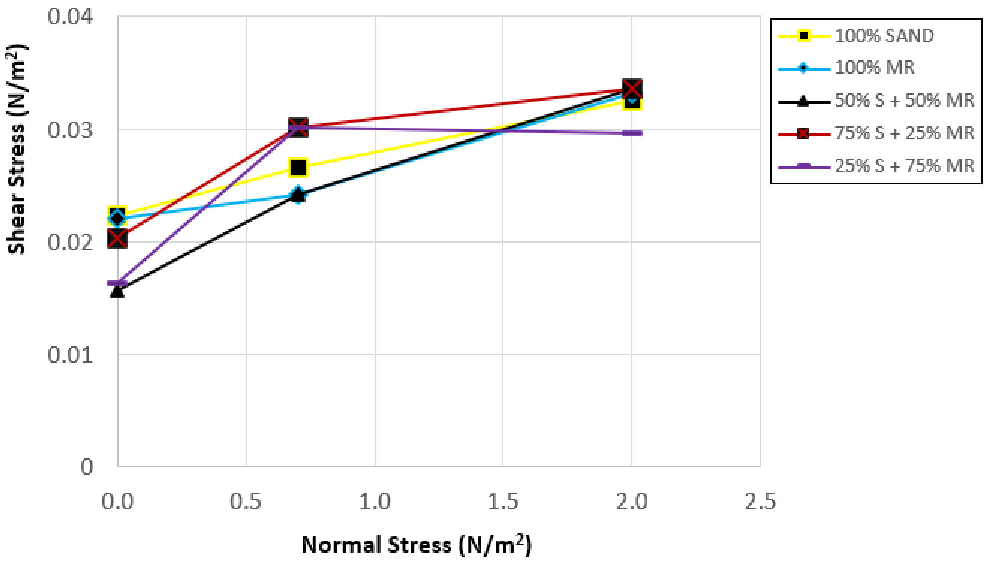


Fig. 9. Graph normal stress versus shear stress for MR (wet sample)

In conclusion, it can be inferred that the shear stress rises with the incorporation of waste rubber content up to 25%, beyond which the shear strength value experiences a decline. This trend is consistent with findings from prior research [18-20]. Furthermore, the normal stress also reflects an increase in particle size, as supported by statements in prior studies [14,15].

3.4 Characteristic Values of Cohesion and Friction Angle

Table 4 presents the cohesion and friction angle values for both GR and MR under dry and wet conditions. In the dry state, the peak cohesion value for GR is 0.0229 kPa, achieved with a composition of 75% S + 25% GR, whereas for MR, it is 0.0224 kPa with a ratio of 50% S + 50% MR. Furthermore, the highest friction angle values recorded are 0.35^0 for GR and 0.41^0 for MR, both obtained at a composition of 25% GR and MR.

Moving to the wet condition, the maximal cohesion value for GR is 0.0192 kPa, observed with 100% GR, while for MR, it is 0.0225 kPa when the ratio is 75% S + 25% MR. Additionally, the highest friction angles are recorded as 0.84^0 for GR at a composition of 75% S + 25% GR, and 0.50^0 for MR with a ratio of 50% S + 50% MR.

Table 4
Characteristic Values of Cohesion and Friction Angle

	Ratio	Dry Sample		Wet Sample	
		Cohesion (kPa)	Friction Angle (°)	Cohesion (kPa)	Friction Angle (°)
GR	100% S (control)	0.0226	0.29°	0.0250	0.09°
	75% S + 25% GR	0.0229	0.35°	0.0106	0.84°
	50% S+ 50% GR	0.0216	0.15°	0.0160	0.12°
	25% S + 75% GR	0.0228	0.11°	0.0107	0.38°
	100% GR	0.0217	0.07°	0.0192	0.12°
MR	100% S (control)	0.0226	0.29°	0.0226	0.29°
	75% S + 25% MR	0.0197	0.41°	0.0225	0.35°
	50% S+ 50% MR	0.0224	0.12°	0.0165	0.50°
	75% S + 25% MR	0.0180	0.27°	0.0201	0.33°
	100% MR	0.0202	0.15°	0.0213	0.33°

Based on the trends revealed in Table 2, it can be summarized that the friction angle increases with the inclusion of waste rubber content in both GR and MR up to 25%, beyond which the friction angle values decrease.

4. Conclusions

This study aims to investigate the attributes of waste tyre rubber as a potential backfill material for retaining walls. Upon analysis, it is evident that the particle sizes of waste rubber GR and MR correspond to the particle size distribution of sand, falling within the range of 0.10 mm to 3 mm. Additionally, the distribution pattern of GR exhibits a slight similarity to the trend of the sand material due to the shape of the particles.

Furthermore, specific gravity measurements reveal that GR 1 has a value of 0.58, GR 2 is recorded at 0.70, and MR is noted as 1.02. These values indicate lower specific gravity compared to sand (2.62) and fall below the 1.50 threshold according to prior research.

On another note, the highest shear stress values for GR and MR are observed at 0.0347 kN/m² and 0.0296 kN/m², respectively, under dry conditions with a 25% ratio. Similarly, the highest friction angle values are recorded at 0.350 for GR and 0.410 for MR, both obtained with a 25% composition of GR and MR in dry conditions. Furthermore, the maximum friction angles are noted as 0.840 for GR with a 25% GR ratio and 0.500 for MR with a 50% MR ratio. The friction angle demonstrates an upward trend with the incorporation of waste rubber content in both GR and MR, peaking at 25%, after which the friction angle values decline. This observed pattern aligns with conclusions drawn from previous studies, substantiating the connection between friction angle and waste rubber content.

In summary, based on the results of the analysis, it can be deduced that the optimal ratio for sand and waste tyre rubber (GR and MR) is 25%, suggesting its suitability as a substitute for sand in backfill material.

Acknowledgement

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