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Shear Strength Characteristics of Engineered Sand Backfill Admixed with Recycled Tyre Wastes

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ABSTRACT

Sand is a versatile material that has highly coping mechanism, making it able to withstand the hostility of environments and variety of climates. Due to the high demand in construction world, sand is exploited vigorously leading to environmental problems as sand is a non-renewable material. Additionally, the case of accumulation of rubber tyre waste in landfills are becoming a major environmental concern. This is because once disposed, rubber tyre wastes release harmful compounds into the environment while also serving as breeding grounds for mosquitoes and ignition points of uncontrollable fires. The current work expounds on the adoption of sand-rubber waste as an initiative to address both issues, simultaneously contributing to the reduction of contamination towards environment. The partial substitution means reduced usage of sand in construction to lessen the demand and exploitation of natural sand. The inclusion of rubber tyre waste in the mixture would also curb the problem of illegal dumping in landfills or open areas. Shear strength parameters of the sand-rubber waste mixture was evaluated using Direct Shear Test, mainly to examine the shear resistance of the innovative composite under vertical load application. From the test results, the optimum mix ratios were identified as 60S40R and 80S20R, for shear strength characteristics that most resemble that of the natural sand or 100S, recording shear strength values of $\tau = 0.444 \tan \phi$ and $\tau = 0.625 \tan \phi$ respectively. For further strength enhancement, an optimal 1.5% steel fibre (10 mm) and 0.5% proprietary soil stabiliser (PMC) could be admixed with the sand – rubber mixture. In conclusion, 40% of sand savings can be achieved for moderate loading construction while 20% savings can be made for high loading applications. The rubber waste substitution of sand also enabled a significant reduction in the dumping at landfills, while enabling effective recycling of an otherwise waste material as useful backfill substitution material for construction purposes.

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1. Introduction
1.1 Research Background

Versatility of sand in providing strength and stability, whilst the high level of durability becomes an advantage in construction, making sand able to withstand, cope well with the hostility of environments and variety of climates [1,2]. Applications of sand in the backfill are important due to the compressed structure of sand which makes it perfect for filling in voids, helps to create a level surface and allows for compaction, ensuring a reliable foundation [3]. However, according to *UNEP* the excessive usage of sand as a non-renewable raw material, exceeding its natural renewal rates [4]. This has become alarming considering the recent report about 32 to 50 billion tonnes of sand that are extracted globally each year where sand is also the second most consumed natural resource on Earth after water [5]. Hence substitutes for sand is always an agenda, such as exemplified in the civil engineering works [6,7]. Moreover, the mining and exploitation of sand have caused severe disruption to the environment, resulting in negative impacts towards flora and fauna, water, air, land and soil itself, including the extreme outstrip supply of sand [8]. In the case of rubber waste from vehicles, the accumulation of rubber waste from automobiles is becoming a major environmental concern too, where 1.5 billion waste tyres are produced worldwide each year [9]. According to Kadri *et al.,* [10], 4 billion rubber tyre waste are currently accumulating in landfills and stockpiles throughout the world releasing harmful compounds into the environment when disposed of in landfills and stockpiles as the rubber tyre waste are not biodegradable. They also serve as breeding grounds for mosquitoes and ignite uncontrollable fires [11,12]. In Malaysia in the year 2019, the Kim Kim River in Johor were polluted badly as the water was contaminated with chemical waste from the pyrolysis process of tyre wastes to produce low-grade oil or fuel oil as a subset of marine oil, which involved burning of used tyres [13].

1.2 Literature Review

Consequently, the literature review of the research laying out about the current study related to sand exploitation and rubber tyre waste that contribute exposure to pollution and decreasing of natural resources. The research also investigates the sources of rubber tyre waste and how it is turn into granules sizes, shear strength analysis of rubber tyre waste admixes with sand and solution to reduce the demand of sand as non-renewable natural resources.

1.2.1 Backfill

Backfilling is the process of filling excavated areas around a foundation or building, using materials like excavated soil, sand-and-gravel mixture or manufactured goods. It provides stability, support, drainage and insulation. Based on Figure 1, it is a crucial step in construction, typically done in layers after foundation pouring and utility line installation [14]. Additionally, backfilling has a variety of methods, but the highlighted methods are trenching compaction, flowable fill and water jetting. However out of these three methods, trench compaction is the suitable one for backfilling geo-structure such as embankment [15]. So far, the trench compaction approach has proven to be effective for sand-rubber mixtures. These admixes have been utilized as trench infill material in some construction projects to minimize vibrations caused by operations like pile driving. Rubber's great damping and energy absorption capabilities make it an attractive material for vibration mitigation studies. However, the success of trench compaction with a sand-rubber mix is determined by the amounts of sand and rubber in the combination. The compaction qualities of the material will be influenced by its composition [16]. These composite materials find usage in road construction, for instance (Figure 1).

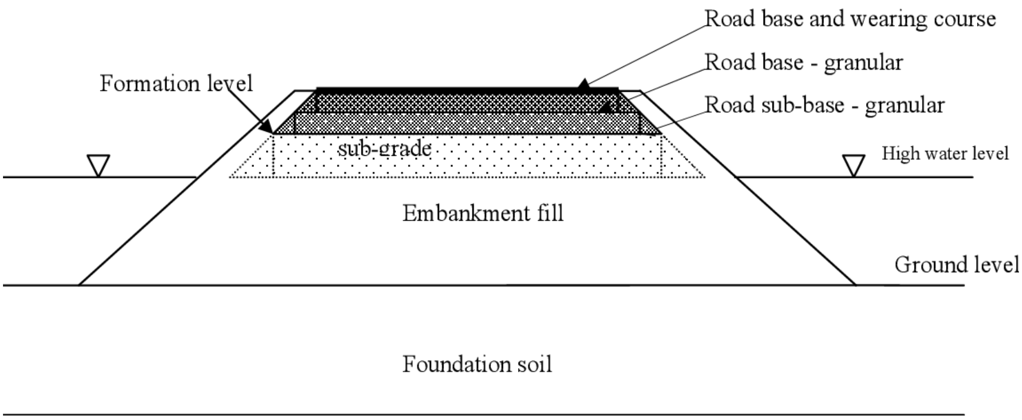

Fig. 1. Road embankment cross-section [17]

1.2.2 Materials for backfill

Materials consist of sand and rubber mixed which is used in the backfill. The sand and rubber mixture are used as an infill, becoming an essential component in construction applications and is primarily used in the backfill to provide stability and support for structures. Additionally, this mixture offers excellent shock absorption properties, making it ideal for impact-resistant surfaces. Sand is generally defined as loose granular material that passes through a 5.00 mm British Standard test sieve. It can either be naturally occurring or the result of the breakdown of rocks or gravels that have undergone either chemical or physical weathering to form sand. Based on the size range and soil grading, type of sand, colour and shape of sand, sand can be divided into various categories [18]. In order to group soils with comparable characteristics or properties, the soil classification system was created based on Figure 2. For example, Unified Soil Classification System (USCS) [19], the American Association for Testing and Materials (ASTM) [20], the British Standard classification system (BS 1990) [21] including the American Association of State Highway and Transportation Officials (AASHTO) [22]. Regardless of this, different classification systems have marginally different cut-off particle sizes and this difference of opinion is primarily caused by the proponent's understanding of the function of soils [23].

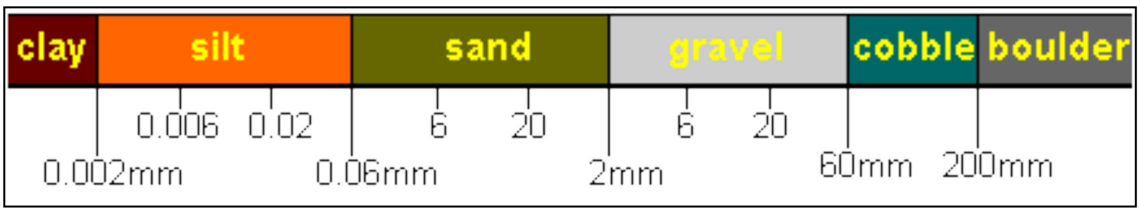

Fig. 2. Size differences between sand, gravel and silt [18]

As for rubber waste, it is a recycled material used in civil engineering, tyre manufacturing, polymer composites and energy sources and there is a pressing environmental issue that requires significant management efforts to address its increasing use [24,25]. This is because rubber waste tyres that have been discarded at the landfills serve as breeding ground for carrier diseases insects and animals like mosquitoes and rodents. It is necessary to address the rubber waste issue because the worn-out natural and synthetic rubber waste accumulates into heaps, naturally degrading over time but taking years to do so [26]. In relations to this, based on Figure 3 the construction industry may find it to be a very practical choice to recycle rubber waste from old tyres. The large amount of waste rubber consumed makes these applications effective at preserving the environment and natural resources [9]. According to a prior study, using shredded rubber waste by turning it into rubber chips as building materials has improved the structural behaviour of natural soil, resulting in strengthened sand and expanded clay soils because rubber particles and soil interact well [9,25]. To further explain, the physical properties of rubber waste, such as shape, size, rigidity and weight-bearing capacity, were modified during the shredding process. The various sizes of rubber chips and rubber crumb are created through the shredding process are used in a variety of civil engineering projects [26].

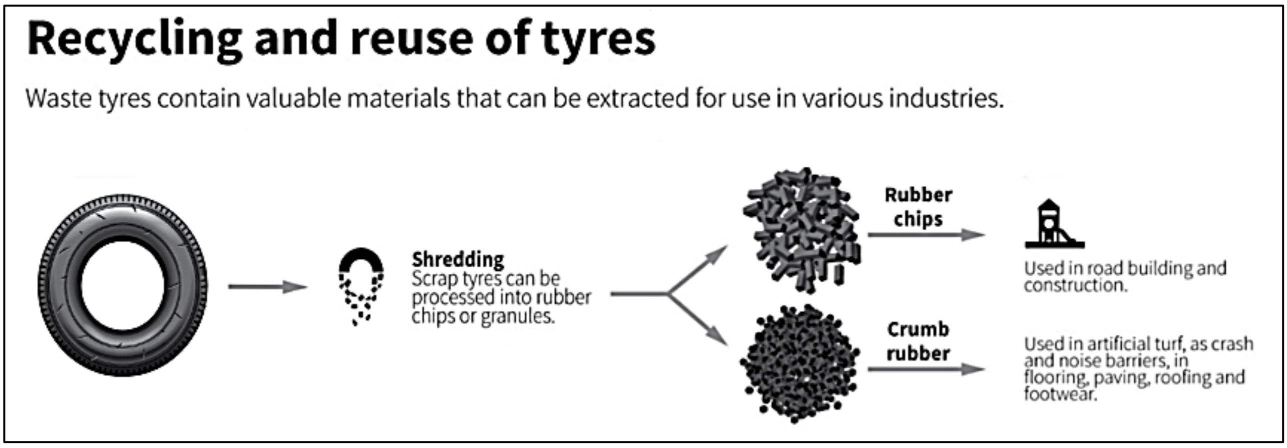

Fig. 3. Rubber waste recycling process [27]

2. Methodology

Referring to Figure 4, the test flow chart is designed to outline the Direct Shear Test testing flow of the sand-rubber mix. Before the test began, the materials used in the study were prepared by sieving the sand and processed rubber granules tyre using siever that is less than 2 mm. This is according to British Standard that limits the size of particles for Direct Shear Test's mould volume that is 25 mm by 60 mm by 60 mm. After that, steel wire is prepared according to its suitable length and percentage content complying with the horizontal displacement (mm) and optimum sand-rubber mix ratio. Then, Polymer Modified Cementitious (PMC) chemical used as soil stabilizer is prepared rightly after optimum sand-rubber mixture with optimum steel fibre content is tested.

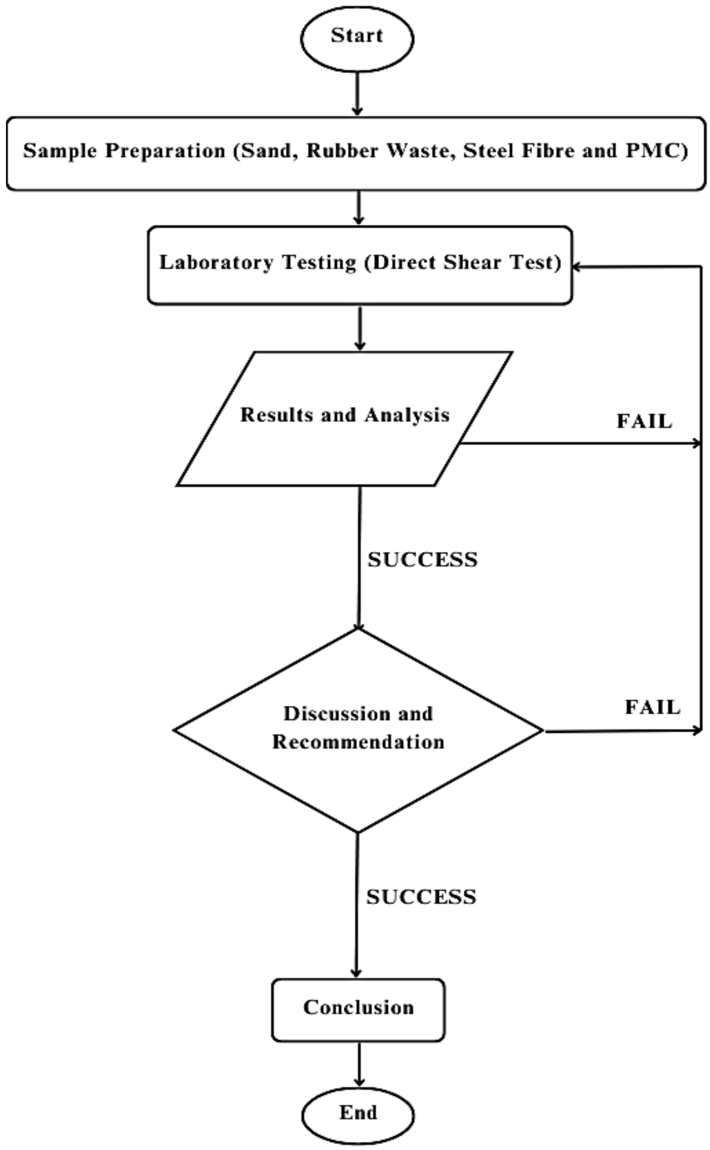

Fig. 4. Test flow chart

The admixture of rubber granules and sand is prepared for six different portions of ratios (Figure 5), that is 90% Sand 10% Rubber Granules (90S10R), 80% Sand 20% Rubber Granules (80S20R), 70% Sand 30% Rubber Granules (70S30R), 60% Sand 40% Rubber Granules (60S40R), 50% Sand 50% Rubber Granules (50S50R) and lastly 25% Sand 75% Rubber Granules (25S75R). The 100% sand (100S) and 100% rubber granules (100R) are included for tested as characteristics guidelines for the mix portions. Once the sand and rubber waste are mixed according to the mixed ratio, the study is limited to the results of Direct Shear Test shear strength analysis evaluated accordance to the British Standard (BS) 1377 Methods of Test for Soils for Civil Engineering Purposes, Part 7: Shear Strength Tests, 1990 Clause 4 and also in accordance to Manual of Soil Laboratory Testing, Volume 2 for Permeability, Shear Strength and Compressibility Tests, Chapter 12 Direct Shear Test.

Fig. 5. Samples of sand – rubber granule mix

Following that, once optimum ratio sand and rubber granules is determined, the optimum ratio is then mixed with steel fibre (SF). Determination of steel fibre length is based on the final horizontal displacement value following Figure 6, referring to where the load reading reaches a constant value during the shearing test. While content of steel fibre is 1% (1SF), 1.5% (1.5SF) and 2% (2SF) respectively. The optimal percentage of steel fibre content will be used to calculate how much steel fibre in grams should be added to the mixture of sand and rubber granules. After the optimum ratio mixed with optimum steel fibre content is determined, the admixtures will be added with PMC. Determination of PMC percentage content is based on the load cell during shearing because the load cell's capacity to withstand shearing is a determining factor; if the capacity is exceeded, the load cell will be unable to handle the shear and may sustain damage. So, the proportion of PMC utilized must be taken into consideration to meet the load cell's capability during shearing, since a high percentage of PMC will cause the optimal mixture of sand and rubber granules with steel fibre to harden. So, the considered PMC percentage is 0.5% (0.5PMC) and 1% (1PMC). Following PMC activation, the percentage of optimum moisture content (OMC) of water should be used. This OMC can be taken from the compaction test conducted.

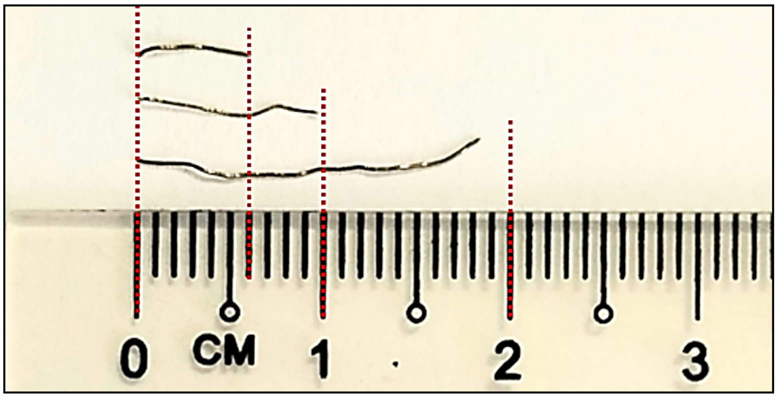

Fig. 6. Length of steel fibre

3. Results

Results are based on shear strength against normal stress of optimum ratio sand and rubber granules (S+R), optimum ratio sand and rubber granules with optimum steel fibre (SR+SF) and optimum ratio sand and rubber granules with optimum steel fibre mixed PMC (SR+SF+PMC). The optimum ratio obtained based on Figure 1 is 60S40R for upper range and 80S20R for lower range.

As regards Figure 7, it can be seen that the ratio of 90S10R and 80S20R exceeds the trendline of 100S. This outcome is not what was expected because the expected ratio of 90S10R and 80S20R is slightly below the trendline of 100S because the percentage of sand is reduced. Furthermore, the angle of friction for 90S10R is 36.39˚ while the angle of friction for 80S20R is 32.06˚. The angle of friction for 80S20R is lower compared with 90S10R as more inclusion of rubber granules in sand mixed reduces the friction between particles as rubber granules have a smoother surface compared with the rougher, angularity surface of sand causing it to rub less between particles and thus produces lesser friction angles than 90S10R. Despite that, both of these ratios are categorized as lower range ratios, in which 80S20R is taken for optimization since both percentage values of rubber granules are closer to each other and not much of a difference in terms of shear strength. The ratio of 80S20R is chosen because the shear strength value is closer to the shear strength of 100S even though with more percentage inclusion of rubber granules and less percentages of sand.

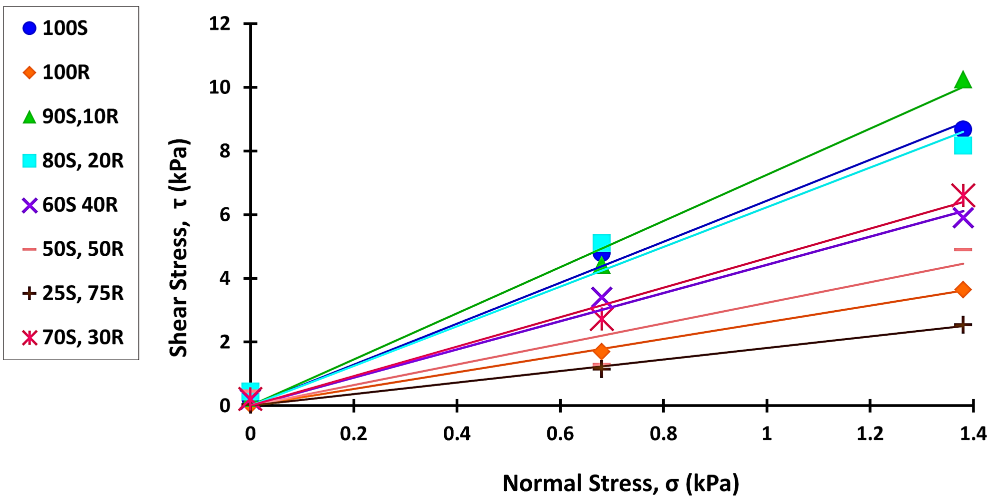

Fig. 7. Shear stress versus normal stress for all ratio

Next, note that the plots of 70S30R and 60S40R are in between the trendline of 100S and 100R. This outcome is expected because the inclusion of rubber percentage is expected to reduce the shear strength and friction of sand-rubber granule particles. Furthermore, the angle of friction for 70S30R is 25.21˚ while the angle of friction for 60S40R is 25.21˚. The angle of friction for 60S40R is unexpectedly the same as 70S30R. Despite that, both these ratios are categorized as upper range ratios, in which 60S40R is taken for optimization since both percentage values of rubber granules are the same to each other and not much of a difference in terms of shear strength. The ratio of 60S40R is chosen as the shear strength value is between 100S and 100R even though with more percentage inclusion of rubber granules and less percentages of sand.

Following is the optimum ratio with steel fibre in which based on Figure 8, 1.5SF content the optimum percentage to be included into optimum ratio of sand and rubber granules mix. This is because 2SF will become residues in the mix whereas 1SF is not enough to increase shear strength and act as structure for the mix. For the length of steel fibre, 10 mm length is chosen as referring to the final value of horizontal displacement (mm) where load cell becomes constant during shearing. This is because optimal steel fibre length ensures that the particles are securely held together, providing stability and preventing separation during shearing, in which also enhanced strength and durability.

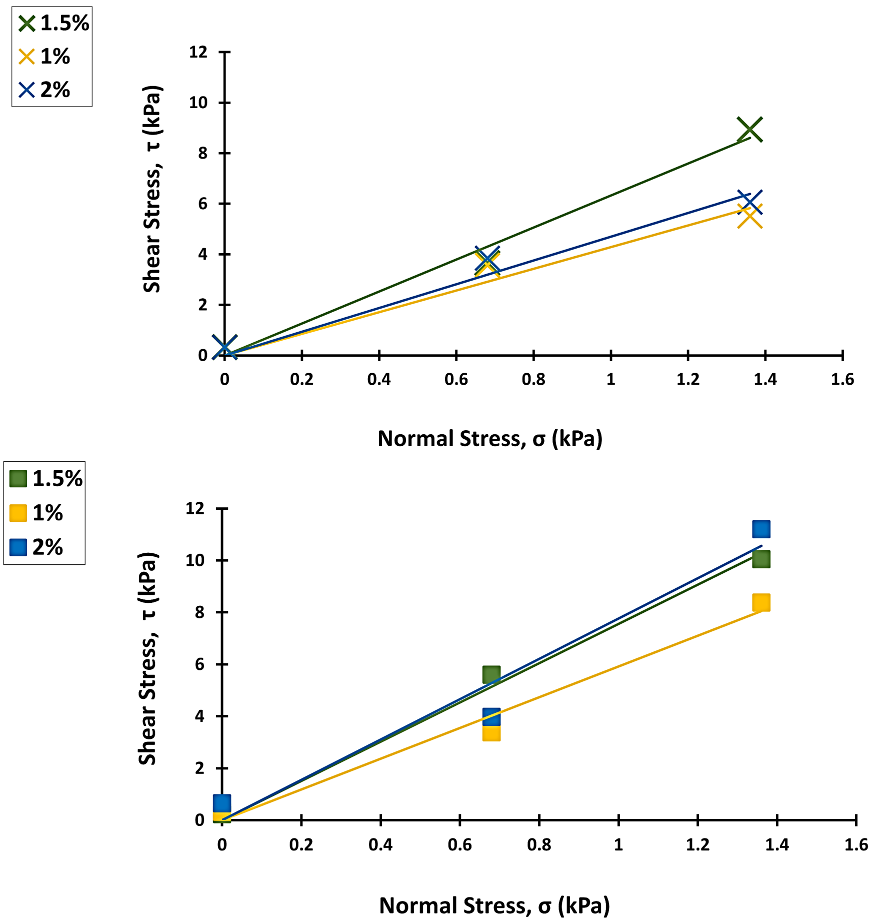

Fig. 8. Shear stress versus normal stress for 60S40R+1.5SF and 80S20R+1.5SF

From then on, the optimum ratio with optimum steel fibre, 60S40R+1.5SF and 80S20R+1.5SF is mixed with PMC in which PMC percentage content is 0.5% (0.5PMC) and 1% (1PMC). However, based on the load cell capacity only 0.5PMC is used in the optimum mix ratio as after one day of curing, the PMC had made the 60S40R+1.5SF and 80S20R+1.5SF harden which is not suitable for testing using Direct Shear Test as it will damage the machine. So, only 0.5PMC is added into the 60S40R+1.5SF and

80S20R+1.5SF. Based on Figure 3, it is found that at three days of curing, the shear strength is the highest for both 60S40R+1.5SF+0.5PMC and 80S20R+1.5SF+0.5PMC. As per Figure 9, this result indicates that at three days of curing, PMC was able to increase shear strength for both 60S40R+1.5SF+0.5PMC and 80S20R+1.5SF+0.5PMC.

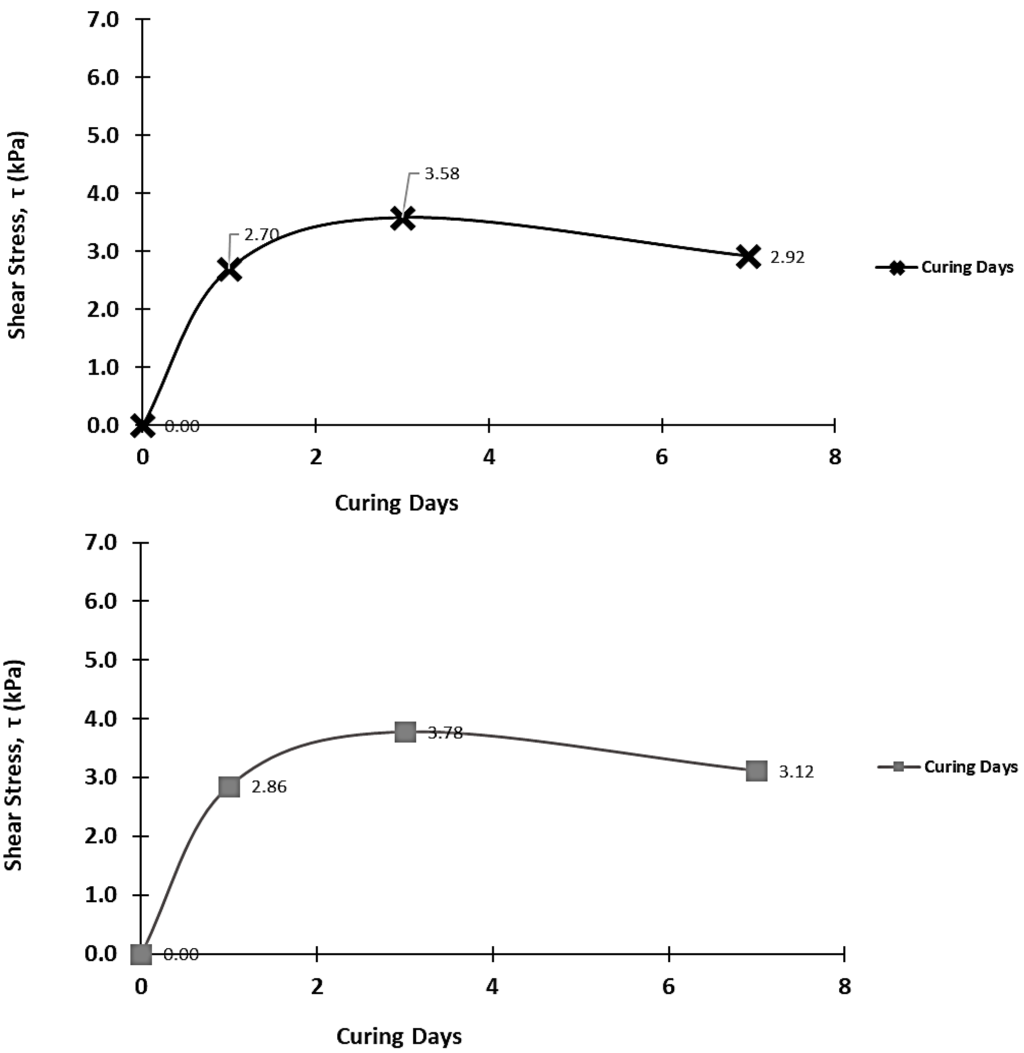

Fig. 9. Shear stress versus curing days for 60S40R+1.5SF+0.5PMC and 80S20R+1.5SF+0.5PMC

However, based on Figure 10, for shear strength versus normal stress, it can be seen that optimum curing days for 60S40R+1.5SF+0.5PMC and 80S20R+1.5SF+0.5PMC is at seven days. This is because based on Jabatan Kerja Raya (JKR) standard, 7 days of curing is the optimum curing time for the stabilizer PMC to react and bind the granular particles in a strong matrix.

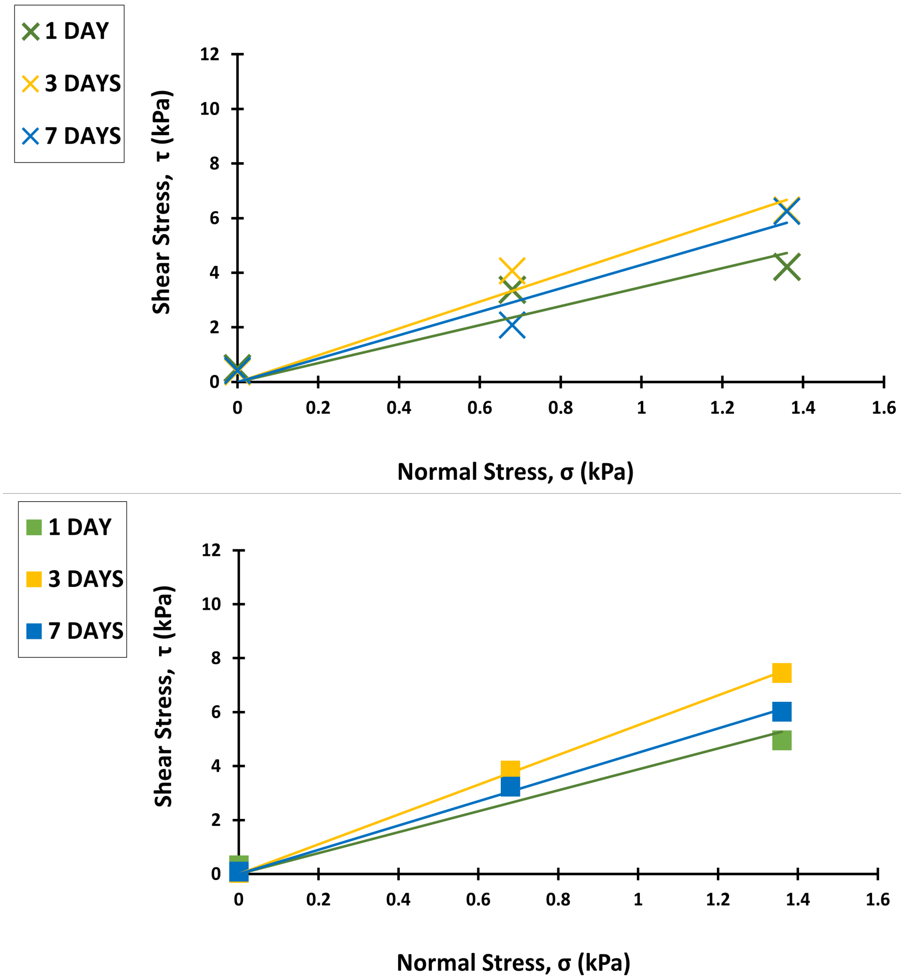

Fig. 10. Shear stress versus normal stress for 60S40R+1.5SF+0.5PMC and 80S20R+1.5SF+0.5PMC

4. Conclusions

In conclusion, using the 80S20R mix ratio in construction not only allows for heavy loads to be accommodated on the roadways like lorries and trailers, but also provides an opportunity to reduce both sand usage and rubber waste. With that, not only can construction projects save up to 20 percent of sand, but they can also reduce the amount of rubber waste in landfills by the same percentage. As for 60S40R, this mixed ratio can be used in construction that can accommodate light loads, such as pedestrian tracks or as a children's playground platform. Regardless of that, by using rubber granules instead of sand, not only can construction projects save up to 40 percent of sand, but they can also reduce the amount of rubber waste in landfills by the same percentage.

Taken together there are a few recommendations for this project improvement, that is to roughen the surface of steel fibres to increase grips of sand and rubber granules particles for better shearing improvement, using scanning electron microscopy (SEM) to analyse the elemental composition of rubber granules and steel fibres to know more about its compound composition and lastly do soaking test for rubber granules water absorption and steel fibres rusting time.

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