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Experimental Study Using Recycled Waste Tyre as Sustainable Clay Soil Stabilisation

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Abstract: Clay presents construction challenges to geotechnical engineers as it shows high compressibility, low shear strength and high level of volumetric changes behaviour. Therefore, the properties of clay need to be improved before it can be used in any type of construction. Clay soil stabilisation using either mechanical or chemical methods are normally adopted to improve its properties. However, some of these methods are reported to be ineffective, expensive and harmful to the environment. In Malaysia, around 8.2 million tyres are dumped in landfill annually. The dumping of tyres will lead to long-term environmental impact. Hence, it is proposed to reuse waste tyres for clay soil stabilisation. This research investigates the effects of recycled waste tyres on the compaction and strength properties of clay soil. Clay soils were firstly mixed with 0, 5, 10, 15 and 20% of waste tyres and each mixed sample was tested for compaction and unconfined compressive strength tests. The results show that the optimum moisture content (OMC) increases, and maximum dry density (MDD) decreases with increasing waste tyre content. Meanwhile, unconfined compressive strength (UCS) reaches a maximum value at 10% waste tyre content and then decreases with further increments of waste tyre. It can be concluded that waste tyres have the potential to be used as an additive for sustainable clay soil stabilisation.

Keywords: Clay, soil stabilisation, strength, sustainable, waste tyre

1. Introduction

Clay is formed by the weathering of primary rock-forming minerals mainly feldspar and micas. The texture of clay is very small which less than 0.002 mm in size and flaky in shape with considerable surface area [1]. Based on mineralogy, stacking arrangement and type of ions present between the clay structure, clay can be divided into three different groups which are kaolinite, illite and montmorillonite. The surface of clay minerals has negative electrical charges which able to adsorb positive charge (cations) in pore water and formed positive charged layer on clay surface known as double layer. The formation of double layer on clay surface significantly affects the physical and mechanical properties of soil [2] . Clay shows different consistency behaviour depending on the water content which significantly affects the plasticity behaviour. Construction on clay soil is very challenging for geotechnical engineers as clay soil is

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very soft, easily compressible and low in shear strength. Some clays even show high swelling behaviour when wet and when dried, cracks start to appear due to shrinkage. Buildings constructed on clay soil are easily to undergo deformation as clay shows the characteristics of having low shear strength, highly compressible and low bearing capacity. Mostly in construction industries, structures that construct on clay soils tend to deform when exposed to additional load as it may cause significant failure to foundation and structures.

As population is growing, the demand for development on unsuitable land such as clay soil cannot be avoided. Therefore, the strength of clay needs to be improved to avoid any potential problems during the construction phase. The common approach to overcome clay problems is to excavate and replace with higher strength material. Various mechanical methods have been carried out to improve clay problems such as surcharge loadings, sand compaction piles, wick drains, stone columns and geosynthetic reinforcements. Meanwhile, chemical methods include mixing clay with stabilising agents such as lime, cement and fly ash are also used for clay stabilisation [3]. Some of the existing methods are argued to take a longer time to achieve the desired properties, incur more cost and ineffective for construction purposes [4][5].

It is crucial to find cheaper and more sustainable solutions to replace the use of traditional methods. Recycled rubber is considered as a promising material to replace the traditional additives besides mitigating the problem of stockpiled tyres in the landfill. International Rubber Study Group (IRSG) forecast that the usage of rubber worldwide will increase at an average of 2.8% per annum from 2017 – 2025 [6]. These numbers may raise concern among environmentalists as it indicates more rubber waste will be generated globally. Due to a large number of rubber waste, landfill is unable to keep up with the increment as disposing rubber is very expensive. This will resort to dumping and open burning in order to mitigate the access of rubber waste which indirectly causing pollution to the air, water and soil. Therefore, it is suggested to utilise the rubber waste for clay soil stabilisation which can overcome improper tyre disposal management and achieve more economical solutions.

Several researchers have reported on the usage of tyres for clay stabilisation. Singh & Rattan [7] studied the effect of shredded rubber tyre waste on clay soil. Three different sizes of width (10, 20, 30 mm) and length (20, 40, 60 mm) were used with varying percentages of 1, 2 and 3%. They found out that UCS reached a maximum value at 1% tyre waste for all sizes used and the values of OMC increased and MDD decreased with increasing percentage of tyres. Ratnam et al. [8] performed strength and settlement analysis using fly ash and different percentages of waste tyre rubber chips on inorganic clay of high compressibility. California Bearing Ratio (CBR) test and Direct Shear tests were performed to measure the strength behaviour. From the Direct Shear test results, the friction angle values of the reinforced sample with fly ash and waste rubber chips were increased from 1% to 6% rubber chips. Once rubber chips exceeding 6%, the friction angle values were decreased. The same trend was also observed for the cohesion values where initially the values increased and later decreased once exceeding 6% rubber chips.

Daud et al. [9] investigated the effect of peat and clay when mixed with 0%, 10%, 20% and 30% shredded tyre chips in terms of compaction, strength and drainage properties. Similar findings were observed in the research done by Rahgozar & Saberian [4] where the strength behaviour increased with increasing amount of shredded tyre chips. Besides, the drainage properties and California bearing ratio (CBR) values were also improved. Compaction test was also performed on treated samples and the results showed that the dry density reduced, and optimum moisture content increased for treated samples at increasing tyre chips amount.

Kumar et al. [10] studied the effect of shredded tyres with lime on clay soil properties. A series of laboratory experiments were conducted comprising Standard Proctor test, Unconfined Compressive Strength (UCS) test and soaked and unsoaked California Bearing Ratio (CBR). The results showed that there was an increasing trend of MDD up to 12% of shredded tyres and constant amount of 10% lime while the OMC increased with the increasing tyre amount. Meanwhile, UCS values showed increasing trend up to 12% shredded tyre and 10% lime and later decreased with further increment. The CBR values were also increased considerably where unsoaked CBR value was found to be maximum at 10.65% for 12% shredded tyre while soaked CBR value was found to be maximum at 6.84% for 12% shredded tyre. Akbarimehr et al. [11] investigated the effect of waste tyre granules and powdered formed on Tehran clay soil. The waste tyres were added at 2, 4, 6, 8, 10, 20 and 30% weight and Proctor compaction tests were performed. The results showed that increasing the added waste tyre powder and granules increased the OMC of the clay and reduced the MDD of the soil. The specimens with added waste tyre powder had better absorption properties compared to the waste tyre granules as powder texture had smaller grain size.

Mohajerani et al. [12] reported that many studies have been done to study the effects of tyre shred mixed with soil using triaxial tests and direct shear tests. The test conditions were varied in terms of type of soil, particle size and rubber content percentage. The results showed that soil mixed with tyre chips alone produced higher friction angle greater than 40^0 when tested using triaxial test. When tyre chips were added with sand, the shear strength were increased further. Masad et al. [13] found out that reducing the particle size of rubber from tyre chips to granulated rubber significantly affects the shear strength performance. This findings was supported by the work done by Akbulut et al. [14] which stated that the addition of rubber tyre chips to clay increased the shear strength parameters which were cohesion intercept of the matrix material and shear modulus.

From a thorough literature review conducted, limited studies looking at the effects of recycled waste tyre granules on Malaysian Clay Soil. Therefore, this research is conducted to investigate the influence of waste tyre additives on the compaction and strength properties of Malaysian Clay soil. The optimum moisture content (OMC), maximum dry density (MDD) and compressive strength is compared for natural (unstabilised) and stabilised clay samples with the addition of waste tyre granules as additives.

2. Test Materials

Clay and recycled clay waste tyre granules were firstly obtained in order to prepare clay samples mixed with different percentages of tyre additives. The tyre additives were mixed with clay samples at 5,10, 15 and 20% proportions. All the relevant laboratory tests were carried out by following the British standard laboratory specifications. The detailed description of clay and waste tyre properties used and sample preparation is described below.

2.1 Clay Soil

Clay soil was sampled and taken from a coastal area located at Klang, Selangor (Fig. 1). The particle size distribution of the collected clay sample is shown in Fig. 2. Based on Unified Soil Classification System (UCSS), the soil is classified as sandy CLAY of very high plasticity. The physical properties of the soil are described in Table 1. The moisture content obtained is agreeable with the findings found by [15] where the moisture content of marine clay is usually varied from 50 to 175%. High moisture content is observed for clay soil as it has large surface area that provides high water-carrying capacity. Specific gravity, liquid limit and plastic limit results are also within the acceptable range as reported by [16].

Fig. 1 - The location of Tajung Harapan within the Klang district where the sample is obtained (blue box)

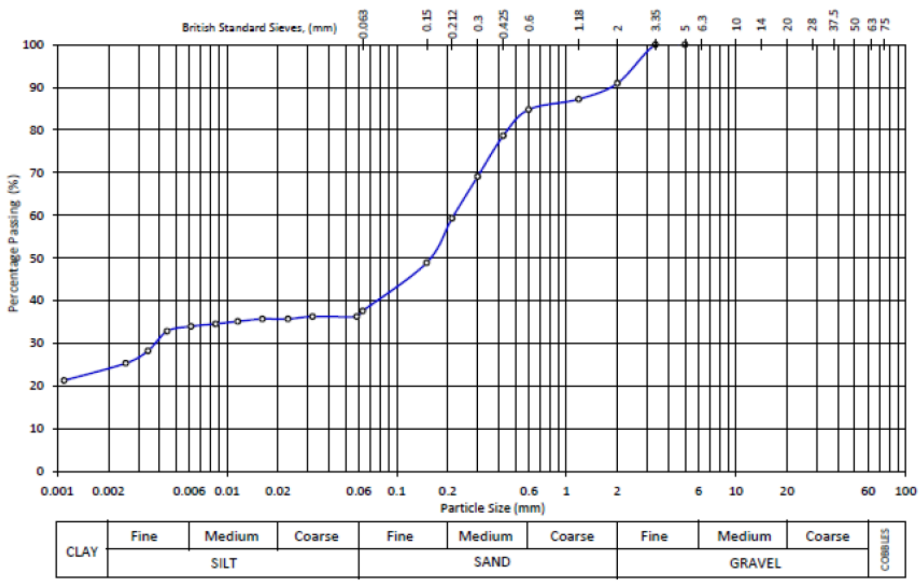


Fig. 2 - Particle size distribution of collected clay sample

Table 1 - The properties of Klang clay soil

Property	Unit	Value
Soil classification	-	Sandy CLAY
Moisture content	%	73.8
Specific gravity	-	2.88
Liquid limit	%	88.41
Plastic limit	%	22.63
Plasticity index	%	65.78

2.2 Waste Tyre

The waste tyre granules used in this study were obtained from a reclaimed rubber industry situated in Klang, Selangor. Fig. 3 shows the mixture of crushed clay soil mixed with recycled waste tyre granules. The recycled waste tyres contain 0.03% steel wires and nylon fibre passing 5-8 mm sieve with a density of 1.15-1.20 g/cm^3.

Fig. 3 - The mixture of recycled waste tyre granules and clay soil

2.3 Preparation of Clay-Waste Tyre Mixtures

Oven-dried clay soil was firstly crushed using an electrical tamping rammer as shown in Fig. 4. Crushed clay particles were then sieved on 5 mm aperture size and mixed with waste tyre granules at 5, 10, 15 and 20% increment. In order to perform compaction test, each mixture containing crushed clay with respective percentage of tyre granules was added with increasing amount of water. The mixed sample was then transferred into a compaction mould in 3 layers and each layer was compacted uniformly for 27 blows. Once compaction test was completed, the samples were then determined for optimum moisture content (OMC) and maximum dry density (MDD). The OMC was used to prepare Unconfined Compressive Strength (UCS) test samples.

Fig. 4 - Oven dried clay is crushed using a tamper before compaction test is performed

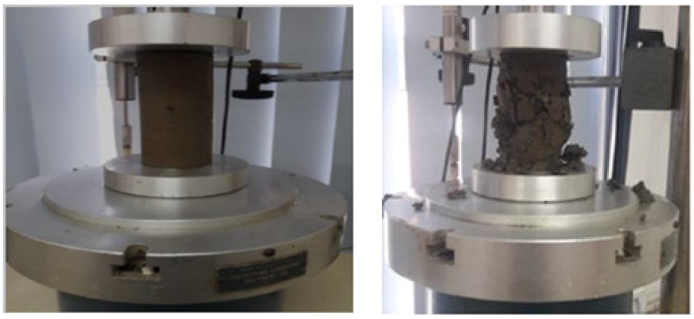
3. Method of Experiments

Compaction tests were performed to investigate the optimum moisture content and maximum dry density of clay and waste tyre granules mixture. For each percentage of tyre added to soil, increasing amount of water was added before compaction was commenced. In order to ensure that water is uniformly distributed, the mixed sample was left for a minimum of 24 hours in room temperature for each water increment. Once mixed with water, sample was then compacted in 3 layers where each layer is subjected to 27 blows. Some mixed sample was also taken for water content test. The same procedures were repeated for a different amount of waste additives according to BS1377:4:1990 [17].

For Unconfined Compressive Strength (UCS) test, cylindrical soil samples having dimensions of 38 mm diameter and 76 mm height were prepared for each percentage of additives. The samples were prepared at optimum moisture content (OMC) obtained from Proctor compaction test. Compacted sample was then extruded as shown in Fig. 5 and UCS cylindrical sample was prepared by pushing UCS mould in the compacted sample.

The UCS test was carried out to determine the UCS of unstabilised and stabilised tyre clay samples according to BS1377:7:1990 [18]. The soil samples were subjected to increasing vertical stress until failure is reached at maximum load. No horizontal stress is applied in the specimen. The maximum load per unit area is defined as UCS. Fig. 6(a) shows the condition of UCS test sample before load is applied while Fig. 6(b) shows the condition of test sample after shearing takes place. The sample exhibits significant failure due to apparent rapture on the soil sample body once UCS test is completed.

Fig. 5 - Extruded sample obtained from compaction test



(a) (b)

Fig. 6 - Test conditions (a) before shearing, and (b) after shearing

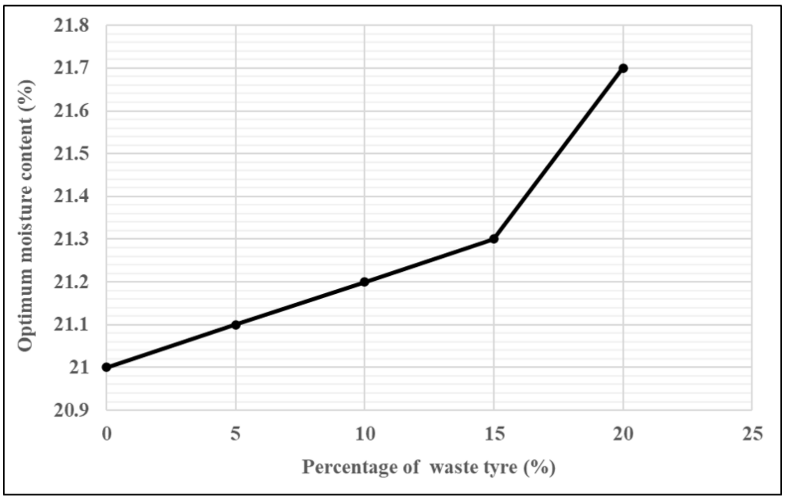
4. Results and Discussion

The effect of waste tyre granules on the optimum moisture content (OMC) and maximum dry density (MDD) of unstabilised and stabilised clay are shown in Table 2 and Fig. 7. For the stabilised samples, the highest MDD is observed for 5% tyre mixture which is found to be 1.58 Mg/m^3 while the sample with 20% tyre mixture shows the highest OMC which is 21.7 %. The OMC and MDD of the controlled sample (unstabilised sample) are 21% and 1.55 Mg/m^3 respectively. The results also indicate that by increasing the percentage of waste tyre, OMC increases and MDD decreases when compared to unstabilised sample. The lower MDD obtained as tyre increases is because the density of waste tyre is lower compared to clay soil. As tyre has high absorption capacity, the OMC increases with increasing amount of tyre content. This trend is agreeable with findings reported by [9], [19], [11].

Unconfined Compressive strength (UCS) test were also conducted for unstabilised and stabilised samples. The results of the tests are shown in Table 3 and Fig. 8. It shows that the UCS values increase and then decrease with increasing tyre content. The maximum UCS value is achieved at 10% waste tyre which is 52.8 kPa and the unstabilised sample shows the lowest UCS value which is 30.2 kPa. The results suggest that the higher amount of waste tyre in clay soil does not necessarily show an increment of stiffness of clay [11]. Although the highest MDD is observed for clay with 5% waste tyre additives, it does not contribute to the highest UCS value. Therefore, MDD values are independent of UCS values. Among the factors that can influence the stiffness of stabilised clay samples are the amount of water used to bind the soil with waste tyre and the intensity of the stress at the contact area between soil grains and waste tyre when axial loading is applied and the optimum amount of waste tyre that caused the significant interlocking effect between soil and tyre waste

Table 2 - The compaction properties obtained for unstabilised and stabilised samples

Sample	OMC (%)	MDD (Mg/m^3)
Natural clay soil	21.0	1.55
Clay + 5% waste tyre chips	21.1	1.58
Clay + 10% waste tyre chips	21.2	1.51
Clay + 15% waste tyre chips	21.3	1.44
Clay + 20% waste tyre chips	21.7	1.40



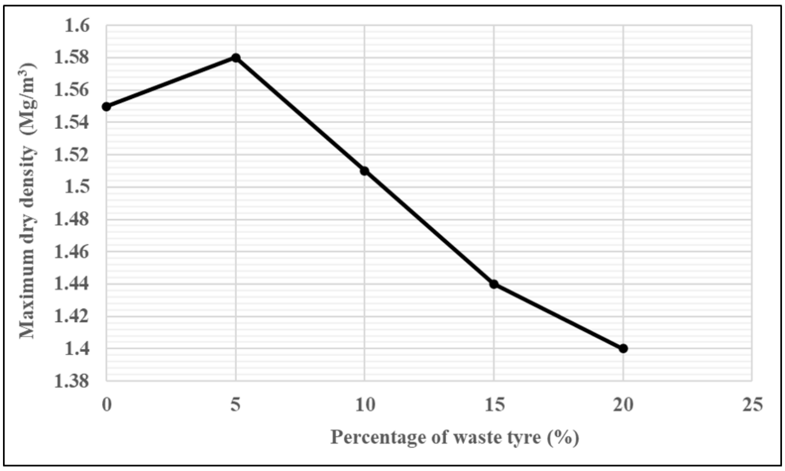


Fig. 7 - The relationship between optimum moisture content and maximum dry density with different percentages of tyre additive

Table 3 - The unconfined compressive strength of unstabilised and stabilised samples

Sample	UCS (kPa)
Natural clay soil	30.2
Clay + 5% waste tyre chips	34.1
Clay + 10% waste tyre chips	52.8
Clay + 15% waste tyre chips	40.3
Clay + 20% waste tyre chips	35.4

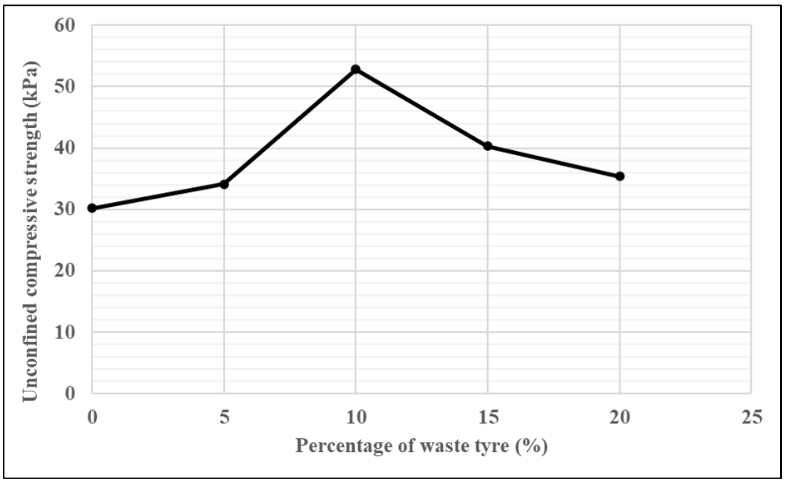


Fig. 8 - The relationship between unconfined compressive strength and different percentages of tyre additives

5. Conclusions and Recommendations

Based on the compaction and unconfined compressive strength test results for unstabilised and stabilised samples, it can be concluded that increasing the amount of waste tyre additives in clay soil increases the optimum moisture content (OMC). This is because waste tyre material is considered for having good water absorption properties. As waste tyre is a lightweight material and known for having a lower density and specific gravity properties than the soil, increasing the waste tyre content in clay soils causing a corresponding decrease in the values of maximum dry density.

In most cases, the highest maximum dry density (MDD) will contribute to the highest value of unconfined compressive strength (UCS) but in this study, that is not the case. This is because the maximum UCS value of 52.8 kPa is achieved at 10% waste tyre additive which is not the sample having the highest MDD value and further increments of waste tyre additives result to decreasing values of UCS.

The durability and sustainability of waste tyres to stabilise other types of soil material should be investigated before using them in practice for construction and building purposes.

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