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IMPROVEMENT OF PROBLEMATIC SOIL USING CRUMB RUBBER TYRE

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ABSTRACT: Construction on problematic soil that has low bearing capacity, low shear strength, high compressibility, and high water-content will interfere with the smooth construction process and will affect time and cost due to repetitive maintenance. Pavement built on problematic soil as its subgrade is exposed to pavement failures, such as fatigue cracking, longitudinal cracking, and pumping, owing to swelling or shrinkage due to moisture variation and differential settlement. Therefore, improvement of the ground needs to commence so as to improve its load bearing capacity, in order to sustain the load on top of it. Consequently, the main aim of this study is to determine the effectiveness of crumb tyre rubber mixed with soil samples as one of the soil stabilisation techniques and to establish the optimum usage percentage of crumb tyre rubber as a stabiliser. Clayey sand soil was mixed with 5%, 10% and 15% of crumb tyre rubber by weight of the soil sample and was tested for physical properties, such as particle size distribution and plasticity index. In obtaining the changes in strength, mixed clayey sand-crumb tyre rubber samples were subjected to compaction and California Bearing Ratio (CBR) tests. The results showed that the increment of crumb tyre rubber percentage as an additive, increased the CBR value and therefore enhanced the strength of the modified soil. However, the crumb tyre rubber stabiliser affected the optimum moisture content and maximum dry density of the modified samples by decreasing their values. The optimum percentage of crumb tyre rubber mixture was found to be 10% by weight at the end of this study. These findings indicate that the measured crumb tyre rubber is suitable for supporting the clayey sand soil for the subgrade of pavement construction.

ABSTRAK: Pembinaan di atas tanah bermasalah yang mengandungi kapasiti galas rendah, kekuatan ricih rendah, kebolehmampatan tinggi dan kandungan air tinggi akan mengganggu kelancaran proses pembinaan dan akan menjejaskan kekangan masa dan wang akibat penyelenggaraan berulang. Jalan raya yang dibina di atas tanah yang bermasalah akan mengalami kegagalan turapan seperti keretakan, rekahan membujur dan pengepaman, disebabkan oleh subgrednya terdedah kepada pembengkakan atau pengecutan akibat perubahan kelembapan dan pemendapan berbeza. Oleh itu, penambah baikan tanah perlu dilakukan bagi mencapai kapasiti galas beban lebih baik untuk menampung beban di atasnya. Oleh itu, tujuan utama kajian ini adalah bagi menentukan keberkesanan serpihan tayar getah yang dicampur dengan sampel tanah sebagai salah satu teknik penstabilan tanah dan menentukan peratusan optimum penggunaan tayar getah sebagai penstabil. Tanah pasir liat sebagai bahan utama dalam kajian ini dicampur dengan 5%, 10% dan 15% serbuk tayar getah mengikut berat sampel tanah dan telah diuji sifat fizikalnya, seperti taburan saiz zarah dan indeks keplastikan. Perubahan dalam kekuatan ditentukan dengan cara menggaul sebatian sampel tayar getah bersama pasir tanah liat dan diuji dengan eksperimen pemadatan dan ujian *Nisbah Bearing California (CBR).* Dapatan kajian menunjukkan bahawa penambahan peratusan serbuk tayar getah sebagai bahan penstabil telah meningkatkan nilai CBR dan sekaligus meningkatkan kekuatan tanah yang diubah suai. Walau bagaimanapun, penstabil tayar getah mempengaruhi kandungan lembapan optimum dan ketumpatan kering maksimum sampel yang diubah suai dengan nilai berkurang. Pada akhir kajian ini, peratusan optimum bancuhan serbuk tayar getah yang diperolehi adalah sebanyak 10% berat sampel. Dapatan ini menunjukkan bahawa tayar getah remah adalah sesuai dalam menyokong tanah pasir liat bagi subgred pembinaan turapan.

KEYWORDS: *California bearing ratio; crumb rubber tyre; ground improvement; problematic soil*

1. INTRODUCTION

In geotechnical work applications, the existing ground will normally form the foundation of the building and road structure. Weak and poor ground conditions cause delays in completing the project and incur huge additional costs. The poor soil often consists of a soft type of soil, such as clay, silt, or peat soil, which have the possibility for differential settlement to occur and are prone to flooding. Ground improvement is important to overcome the poor performance of the site area in order to fulfil the project specification. One of the methods for the improvement of soil is adding a biopolymer mixture, such as rice husk ash, wood ash, crumb rubber tyre and banana fibre to the soil. Biopolymer mixtures are natural polymers created by living organisms and are viewed as environmentally friendly and reasonable materials. Therefore, numerous researchers have carried out research work related to the utilisation of biopolymer mixed with the soil to enhance the stability of the soil. Ample works have succeeded in their findings.

The effectiveness of adding crumb tyre rubber has been found in some research works carried out by Banzibaganye [1]. Shredded rubber tyre with two types of sand and, as a result, the materials produced showed a decrease in weight, adequate stability, low settlement, better drainage, and the preservation of energy and resources. The utilisation of the stabiliser also enabled proper waste disposal and tyre management that subsequently led to a positive effect on the environment [1]. The use of crumb rubber as a stabiliser substantially lessened the burden of waste tyre disposal and encouraged the establishment of an economical method for soil stabilisation purposes [2]. Therefore, this initiative also contributed to the reduction of construction costs and would lead to a cleaner environment without worrying about environmental degradation due to the improper disposal of solid waste tyre. Rubber tyres posed serious negative effects on the environment, health and aesthetics due to the huge quantity of rubber tyre waste. These non-biodegradable materials are often left to pile up in disposal sites, and provide a conducive place for mosquito breeding, as well as posing a fire risk [3]. As a result, it is advantageous to investigate crumb tyre rubber, as soil stabiliser material because it is one of the options for converting waste tyres for beneficial use.

According to Al-Neami [4], the specific gravity test, compaction test, direct shear test, and California Bearing Ratio (CBR) test were conducted to identify the properties of the mixed soil-crumb tyre rubber. As a result, when the percentage of crumb rubber increased, the specific gravity, dry density, and optimum content also decreased. However, the shear strength and CBR value increased. The author also mentioned that lateral earth stress on retaining walls was reduced when using the tyre chips as fill material [4]. Besides, Hambirao and Rakaraddi [5] stated that the compressive strength of mixed cement-crumb tyre rubber increased from 74 kPa to 201 kPa for 2% cement replacement and 246 kPa and 328 kPa for 4% and 5% cement replacement, respectively, by adding waste tyre rubber chips. The cement replaced by 5% of rubber tyres had the highest compressive strength.

Ravichandran et al. [2] analysed the properties of mixed clay-crumb tyre rubber by carrying out a compaction test and CBR test. Based on the compaction test, increase in the percentage of crumb rubber resulted in a decrease of maximum dry density and optimum moisture content of the clay. However, the CBR value increased when the addition of crumb tyre rubber was added up to 10% [2]. Furthermore, Singh et al. [6] mentioned that the strength of soil increased with no effect on the strain when the percentage of crumb rubber was increased. The value of unconfined compressive strength increased for soil at 20% mixture of crumb rubber.

Based on the presented literature, the objective of this research was to determine the effectiveness of crumb tyre rubber when blended with clayey sandy soil. Generally, clayey sand attributes provide significant engineering properties and have high plasticity, cohesiveness, high water absorbency, high compressibility, and low shear strength, which makes the soil unsuitable for construction. The clayey sand properties were improved by the application of 5%, 10%, and 15% of the soil weight in each testing standard. Laboratory testing was performed to test the physical properties of soil samples, as well as to investigate the additive's performance in improving the efficiency of soil samples. From the data collection and analysis, the optimal percentage design of crumb tyre rubber to be mixed with the soil samples in order to produce an excellent mixture proportion for practical purposes could be established. Additionally, the crumb tyre rubber mixtures were observed to be aligned with the Specification for Road Works (JKR/SPJ/2014) set by the Malaysian Public Works Department (PWD), whereby the recommendation for pavements in Traffic Class T2 until T5 is not to be less than 5%. While, for large traffic volume, such as Traffic Class T4 and T5, the required minimum subgrade strength of 12% CBR value should be ascertained [7].

2. METHODOLOGY

2.1 Desktop Study

A desktop study was carried out to identify the best soil stabiliser and to select a suitable site to collect weak soil samples. The crumb tyre rubber was chosen as a soil stabiliser for this study because of its performance in terms of improving the properties of the soil sample, such as reducing the dry density, specific gravity, and optimum moisture content. This is due to the lightweight crumb rubber tyre properties and its ability to decrease the lateral earth pressure of retaining walls when it is used as a fill material [8,9]. Furthermore, Tiwari et al. [10] stated that the crumb tyre rubber had a partial gluey attribute that could stick the materials together for long-term hardiness. Meanwhile, Keerthi and Doodala [11] assumed that the flexibility of rubber tyres and their adaptability to nature, combined with the properties of difficult decomposition and flammability, drew the attention of geotechnical engineering researchers.

2.2 Sample Collection and Preparation

The soil samples collected for this study were weak ground soil with a soft texture and cohesive soil properties that primarily consisted of clay, clay loam, sandy clay loam, and so forth. The soil sample was collected from the Sungai Pusu riverbank at the International Islamic University Malaysia (IIUM), Gombak campus, as shown in Fig. 1.

Fig. 1: Location of soil sample collected.

The crumb tyre rubber, which was processed and supplied by Yong Fong Rubber Industries Sdn Bhd in Port Klang, Selangor, was the other main material used in this study. Unwanted elements other than granular rubber were sorted and eliminated during the processing. The granular rubber was shredded into various sizes according to its functional ability. This research used 40 mesh sizes of crumb tyre rubber, as depicted in Fig. 2, to provide decent interlocking properties between the tyre rubber and soil sample. The crumb tyre rubber was added, consisting of 5%, 10%, and 15% by weight of samples for each testing standard.

Fig. 2: 40 mesh of crumb tyre rubber.

As the soil samples were taken from three different spots in the selected areas, the average result for each sample is considered to represent the type and properties of weak ground. Table 1 simplified the ratio of soil samples and crumb tyre rubber to be prepared for the experimental study.

Table 1: Percentage of soil sample and crumb tyre rubber with sample label

Soil percentage [%]	Crumb tyre rubber percentage [%]	Soil sample CS-Clayey sand
100	0	CS-CR0
95	5	CS-CR5
90	10	CS-CR10
85	15	CS-CR15

2.3 Particle size distribution

A particle size distribution test was carried out to determine the grading characteristics of soil samples with a range of different sizes and shapes. In this investigation, two methods were used in finding the particle size distribution: sieve analysis and hydrometer test. Sieving analysis is commonly used to determine the particle size distribution of the coarse, large-sized particles, while hydrometer test is used for the finer size of particle that passes the 75 µm sieve. The results of this testing will be plotted on a particle size distribution curve to indicate the percentage of the finer and coarser particles within the soil sample.

Sieve analysis was conducted in this study to find the distribution of particles larger than 75 µm or 0.0075 mm and it was performed for the three raw soil samples collected from three separate points. The mechanical shaker, sieve stack, electronic weighing balance, and prepared samples were important apparatus and materials in conducting the test. Prepared samples that had been oven-dried were poured into a series of sieve stacks in the mechanical shaker. The mechanical shaker was left operating for about 5 to 10 minutes to separate the soil particles into their appropriate sizes in each stacker. Retained soil on every stack was weighed and recorded to enable the particle size distribution graph to be plotted, which is the diameter of the particle versus the percentage of the passing particle. Sample preparation and test procedures for this sieve analysis complied with the requirements of the American Society for Testing and Materials (ASTM) C136 standard.

A hydrometer test was conducted to determine the finer particle size distribution of soil that passed a 0.075 mm sieve. The hydrometer test is more effective when dealing with finer grain size of soil samples compared to sieve analysis. It is impracticable to design the sieving stack with such a small hole. This test was also conducted due to the presence of clay in the soil samples and the standard procedure of this test was based on the ASTM D7928 standard. In this study, prepared soil samples that passed a 0.075 mm sieve were selected, and about 37.5 gm of the sample was mixed with distilled water in a graduated cylinder and allowed to suspend. The hydrometer reading was taken by observing the meniscus formed by the suspension and the hydrometer stems to the nearest 0.0001 according to the standard elapsed time reading schedule and the temperature reading was taken periodically. Moreover, the reading for zero correction and meniscus correction were performed to avoid systematic errors. The zero correction and meniscus correction for this test were 0.9980 and 0.0002, respectively. The results from this test were then averaged to understand the properties of the samples, as illustrated in the particle size distribution graph. Both results were combined and plotted on one graph of the particle size distribution curve.

2.4 Atterberg Limits Test

The Atterberg limits test was performed to describe the consistency and plasticity behaviour of the soil samples in which the soil changes between solid, semi-solid, plastic and liquid states. The liquid limit (LL) results and plastic limit (PL) values could be obtained from the test. The difference between both values resulted in the plasticity index (PI) value, which measured the plasticity properties of the soil sample and provided the soil samples classification. The procedure of this experiment precisely followed the requirements, as stipulated in the ASTM D4318 standard.

The PL value is the measurement of soil water content at the boundary between the semi-solid state and plastic state. It was determined by rolling the soil sample into a thread of 3.2 mm diameter on a flat glass surface by hand without breaking the sample. Consequently, the soils were mixed with crumb tyre rubber, consisting of 0%, 5%, 10% and 15% by weight of samples and underwent the process of rolling until the soil disintegrated under pressure and could not be moulded into a 3.2 mm diameter measurement. The completed rolled soil samples were placed in a container and weighed. Lastly, the water content was determined the next day after drying the samples in an oven at 105 ºC.

The LL test is to identify the ability of water content in the soil that changes the soil properties from plastic to liquid states. This test was measured using the Casagrande cup method. The samples were moistened with about 25 drops of water prior to laying them in the Casagrande cup and cutting the soil into a V-shaped line in the centre using flat grooving tools with a gauge. The mechanical Casagrande cup was raised and dropped from a height of 10 mm at the rate of two drops per second. The process was repeated until the cutting section joined at about 13 mm in length. The number of drop-offs required to connect the cutting edge should be counted, which should be between 15 and 35 drops. Connected samples were taken and weighed. Next, water content was obtained after drying the sample in the oven at 105 ºC for 18 to 24 hours.

The PI measures the plasticity properties of the soil sample. The plasticity index value could be calculated from the difference between the LL index and PL index as stated in Eq. (1).

$$PI = LL - PL \tag{1}$$

2.5 Proctor Compaction Test

The Proctor compaction test is the procedure of densification of soil to decrease the air voids. In this present study, the test investigated the soil samples by mixing of crumb tyre rubber to identify its compaction attributes of the optimum moisture content and maximum dry density [12]. The standard procedure for this experiment was according to the ASTM D698 standard. The soil samples were thoroughly mixed with crumb tyre rubber consisting of 5%, 10%, and 15% by weight of the prepared soil samples, together with the calculated amount of water. The moist crumb tyre rubber-soil mixture was inserted into an empty mould in three layers. Uniformly distributed, 25 blows were imposed on the surface of each layer using a 2.6 kg rammer. Some of the compacted layers were extracted to test for the moisture content of the soil sample by oven-drying the soil sample overnight.

Based on the data collected from the experiment, a chart was drawn between the water content and dry density to achieve maximum dry density and optimum water content. The findings can be used to develop test samples for the CBR test.

2.6 California Bearing Ratio (CBR) Test

The CBR test was performed to decide the CBR value by accomplishing a laboratory load penetration test, as specified in the ASTM D1883 standard procedure. The CBR value indicated the mechanical strength of the soil sample and crumb tyre rubber mixtures due to the applied pressure from a plunger on the top surface of the soil. A higher CBR value indicates harder soil that can withstand more load.

In this research, prepared samples were taken at about 5 kg in weight for every sample and blended evenly with 0%, 5%, 10% and 15% of the crumb tyre rubber. An amount of water was added to the mixture according to the result obtained in the Proctor compaction test. The modified soil was then poured into a mould in five layers and each layer was compacted with 56 evenly distributed blows from a 4.89 kg hammer. The CBR is the proportion of force per unit area required to infiltrate a soil sample using a round hammer at a rate of 1.25 mm/min. The compacted modified soil in the mould was positioned on the CBR machine for data collection of the plunger force that the soil could bear.

From the CBR results, a graph was produced. The percentage of crumb tyre rubber that best illustrated the effect of the added crumb tyre rubber on the soil was plotted against the CBR value in order to determine the ideal percentage of added crumb tyre rubber. The CBR value was used as an index of soil strength and bearing capacity. Eq. (2) was used to calculate the CBR value.

$$CBR(\%) = \frac{\text{load carried by specimen}}{\text{load carried by standard specimen}} x100 \quad (2)$$

where,

Load carried by standard specimen:

For 2.5 mm penetration = 13.2 kN

For 5.0 mm penetration = 20 kN

3. RESULTS AND DISCUSSIONS

The soil samples collected from the riverside of Sungai Pusu were mixed with crumb tyre rubber with different percentages by weight (0%, 5%, 10%, and 15%) and were tested in several experiments based on a standard procedure. Before mixing, the weights of the soil sample and crumb rubber tyre were calculated in order to prepare for the soil-rubber tyre mix proportion that was utilised in the sieve analysis, hydrometer test, Atterberg limits, Standard Proctor compaction, and CBR tests. The goal of the investigation was to verify the effectiveness of crumb tyre rubber as soil sample stabilisers.

3.1 Particle Size Distribution

Before determining the result of the particle size distribution percentage, the three samples collected from the chosen areas were subjected to two tests, which were the sieve analysis and the hydrometer test. The results from the two experiments were combined to plot the particle size distribution graph, as mentioned in the previous chapter. From the curve, the dissemination percentage of the particles could be divided into four categories: gravel, sand, silt, and clay. The particle size distribution graph for the parent soil is shown in Fig. 3.

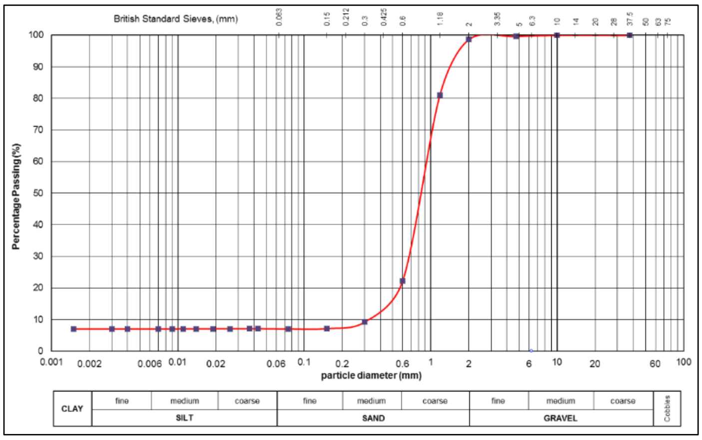

Fig. 3: Particle size distribution graph.

The particle size percentage of each category was tabulated in Table 2. Table 2 clearly showed that the highest particle percentage was sand (84.54%), followed by clay, gravel and silt, which were 6.99%, 5.51% and 2.96%, respectively.

Table 2: Percentage of particle size distribution

Type of particle	Percentage from total amount [%]
Gravel (>2 mm)	5.51
Sand (0.06 - 2 mm)	84.54
Silt (0.002 - 0.06 mm)	2.96
Clay (<0.002 mm)	6.99

Based on the particle distribution graph, uniformity coefficient, C_u and coefficient of gradation, C_c for the soil samples were calculated and resulted in values of 5.81 and 0.86, respectively. As the sample retained more than 50% of the No. 200 sieve, the soil was categorised as coarse-grain clayey sand according to the Unified Soil Classification System (UCSS) (ASTM Test Designation D2487). The values of C_u and C_c indicated that the soil sample was poorly graded sand and prone to settlement and had problematic water-clog areas. In order to have good interlocking between poorly graded soil and crumb tyre rubber, the waste tyre had to endure the mechanical machine grinding process and passing through standard size to achieve finer and more uniform particles of the crumb tyre rubber [4].

3.2 Atterberg Limits Test

The LL test and PL test were conducted in order to determine the plasticity index of the soil samples and crumb tyre rubber mixtures. The Atterberg limits test results for the soil samples are illustrated in Table 3.

Table 3: Atterberg limit results

Soil sample	Liquid limit [%]	Plastic limit [%]	Plasticity Index
CS-CR0	63.9	41.4	22.5
CS-CR5	44.2	27.7	18.6
CS-CR10	44.0	26.5	17.5
CS-CR15	25.5	9.8	15.7

Based on the results shown in Table 3, analysis was performed on the soil characteristic identification related to the plasticity traits. It was identified that CS-CR0 was characterised as clay with high plasticity (CH), while the modified soil that contained 5% and 10% of crumb tyre rubber was found to be clay with intermediate plasticity (CI), followed by CS-CR15, which was identified as clay with low plasticity (CL). The results showed that the soil-crumb tyre rubber combination exhibited a lower plasticity state and a higher add-on amount of the additive might lead to an enhanced shear strength of the altered soil compared to the basic soil. Overall, it could be seen that LL, PL and PI were all increased as the percentage of crumb tyre rubber content increased. The results corresponded with a previous study by Sarvade and Shet [13]. This pattern revealed that the properties of the crumb rubber tyre, as an additive contributed positively to the changes in the consistency of the soil with varying moisture content.

3.3 Standard Proctor Compaction Test

The compaction test was carried out for the soil samples supplemented by a crumb tyre rubber of size 40 mesh in different mix percentages to determine and compare the optimum moisture content (OMC) and maximum dry density (MDD). Heavy tamping using a rammer with a weight of 2.6 kg applied with 25 blows was distributed over the surface of each layer.

The outcome of the Standard Proctor compaction test for the samples were tabulated in Table 4 according to the percentage of the additives mix.

Table 4: Result of compaction test

Soil sample	CS-CR0	CS-CR5	CS-CR10	CS-CR15
Optimum moisture content [%]	16.18	17.32	17.13	14.74
Maximum dry density [Mg/m^3]	1.64	1.63	1.54	1.57

Figures 4 and 5 define the OMC and MDD graph of the sample with their percentages of modification, respectively. The pattern showed an increasing trend in moisture content up to a particular point and began to decrease thereafter.

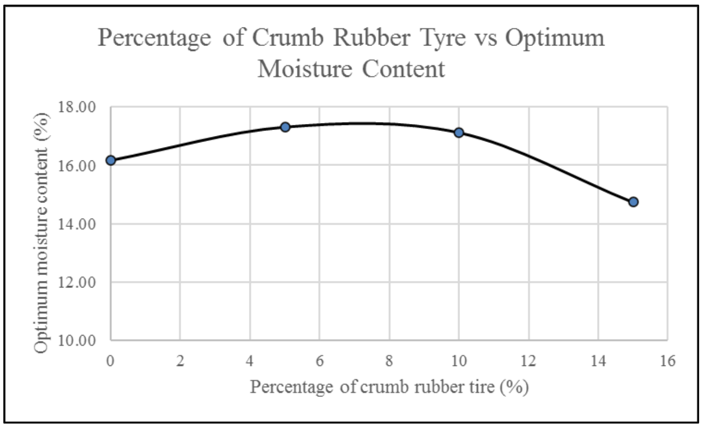

Fig. 4: Optimum moisture content graph.

Figure 4 showed the trend of moisture content increasing until 7% of the crumb tyre rubber and decreasing afterwards. However, there was a difference between the percentage of OMC at 5% and 10% crumb tyre rubber, which were recorded at 17.32% and 17.13%, respectively. Further addition of stabiliser to the samples showed a decline in OMC until the lowest value was at about 14.74%, similar to the results obtained by Vasavi et al. [14]. This was due to the excessive amount of rubber that caused a disruption and led to a disturbance in the mixture's ability to absorb [15].

The results of the MDD were clarified in Fig. 5, whereby generally the curve demonstrated a declining trend with the addition of more crumb tyre rubber. The decrease might be due to the benefit possessed by crumb tyre rubber as a fine and light material capable of holding 1.02 to 1.27 of specific gravity [16]. Furthermore, Mohammed et al. [3] supported the decrease of the crumb tyre rubber dry density of the modified soil mainly due to the density of the crumb tyre rubber that was found to be lower than that of raw dune sand [3] and it was considered as a lightweight fill material based on its nature [8]. This argument was bolstered by Ravichandran et al. [2], who found that the lower specific gravity of crumb rubber led to a low maximum dry density. However, the CS-CR15 sample had slightly increased the dry density to about 0.03 Mg/m^3.Overall, the maximum dry density value of the modified sand-crumb tyre rubber did not show significant differences from the original soil. The differences were in the range of 1.54 to 1.64 Mg/m^3.

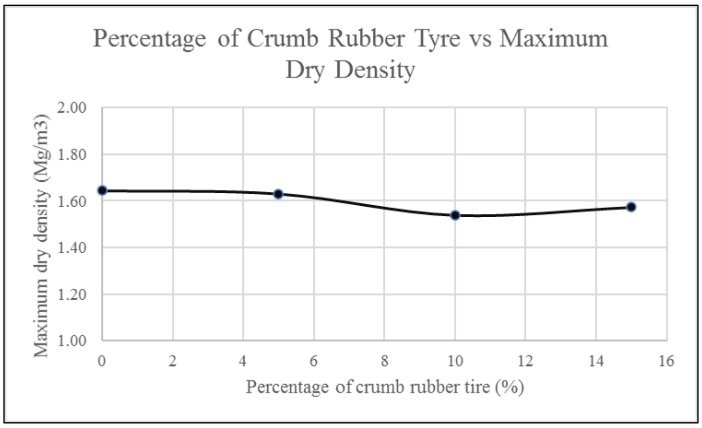

Fig. 5: Maximum dry density graph.

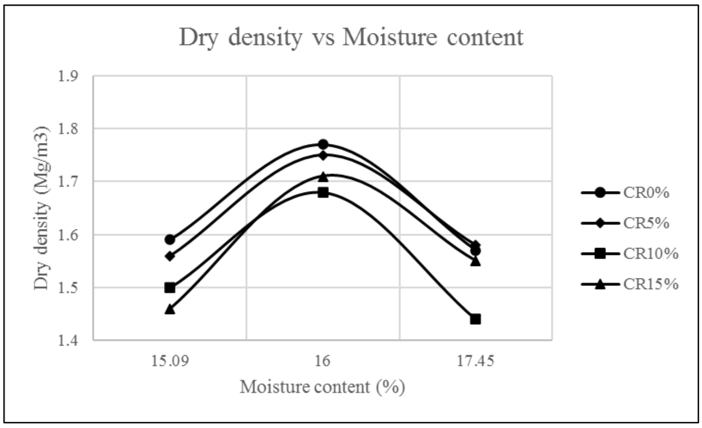

Fig. 6: Compaction curve.

Figure 6 illustrates the compaction curve that consists of the dry density-moisture content relationship with the altered percentage of crumb tyre rubber at 0%, 5%, 10%, and 15%. Overall, there was a substantial increase in dry density along with an increase in moisture content of about 16% and the graph declined subsequently. Both parameters of MDD and OMC revealed minimal differences, with the values varying from 1.68 Mg/m^3 to 1.77 Mg/m^3 and 15.09% to 17.45%, respectively. Additionally, the graph displayed that by adding the crumb tyre rubber, the maximum dry density of the modified soil was lower compared to the parent clayey sand sample. This was because the weight of the crumb tyre rubber, which was originally known to be light, affected the density of the modified soil.

3.4 California Bearing Ratio (CBR) Test

The results for force on the plunger versus penetration of the CBR test for the clayey sand sample with the addition of 0%, 5%, 10%, and 15% crumb tyre rubber is illustrated in Fig. 7. The figure demonstrates that the origin sample, as well as the modified sample showed a mounting curve through the experiments. It could be seen from the graph that the most obvious positive rising trend was the CS-CR10 sample which had 10% of the crumb tyre rubber. This positive trend was also proven by Al-Neami [4], who stressed that generally, the curve for reinforced sand samples increased as the percentage of crumb rubber and soil increased because the mixture tends to create bonds between them, leading to the fact that the modified mixture was able to sustain more load compared to raw soil. Moreover, the stress applied over the soil surface was dispersed and distributed evenly towards the crumb tyre rubber and the soil. Increasing the crumb tyre rubber quantities resulted in less stress being held within the soil. Furthermore, Al-Bared et al. [17] agreed in their studies that soil samples supplemented with crumb tyre rubber could enhance the CBR value and be directed towards the reduction of pavement thickness and project costs.

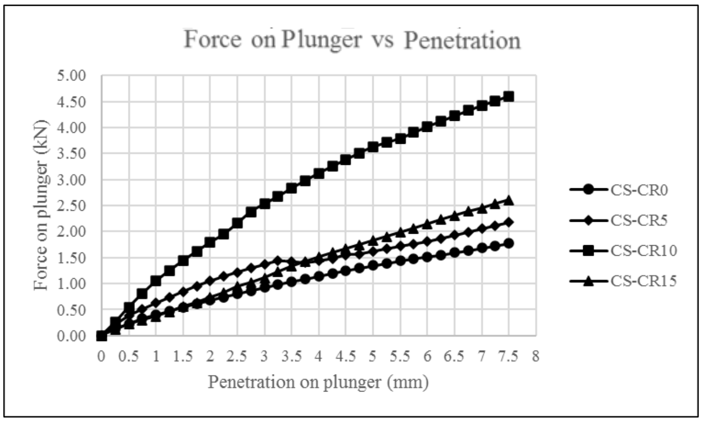

Fig. 7: California Bearing Ratio result.

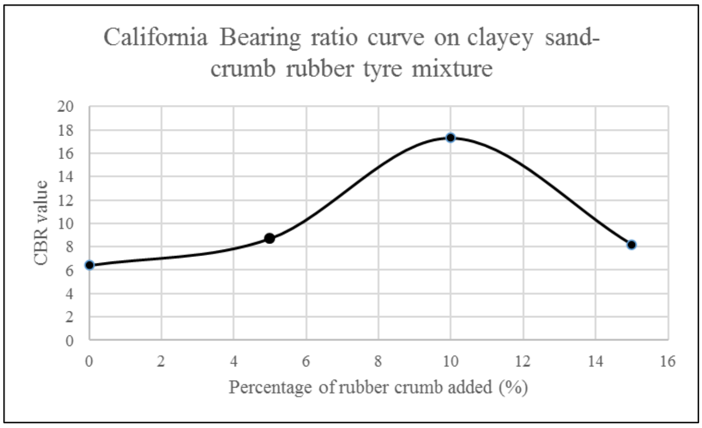

Fig. 8: Effect of percentage of crumb rubber added on CBR value.

To sum up the graph of crumb tyre rubber -soil mixtures with the CBR value relationship, it could clearly be seen that the rising trend in CBR value for the clayey sand samples was steadily persistent up to 10% of the crumb tyre rubber mixture, as shown in Fig. 8. The increase in the trend of CBR value was due to the small difference between the sizes of soil and the sizes of rubber crumb that produced a decent interlocking between them, and thus, could fill in the air void. Consequently, this factor resulted in the higher strength of the soil to withstand an applied load. However, the upward trend started to decrease after further addition of crumb rubber. According to Juliana et al. [7], the fall pattern was due to the presence of higher crumb rubber content that might cause greater compressibility in the mixture. The highest CBR value achieved was approximately 17 at 10% of crumb rubber addition, while the lowest CBR value belonged to the raw clayey sand sample, which was at 6. This showed that all mixtures (CS-CR0, CS-CR5, CS-CR10 and CS-CR15) had satisfied the minimum condition of PWD's standard.

Furthermore, from the above illustration, it could be stated that the optimum percentage of adding rubber crumb to the soil was 10% by weight in order to improve the weak soil. This was because the highest peak of each sample was achieved when the addition of 10%

crumb tyre rubber to the samples was accomplished by the weight of the samples in each testing standard.

4. CONCLUSION

This study was conducted to design the most suitable and ultimate functional samples out of a mixture of crumb tyre rubber stabiliser and clayey sand. Crumb tyre rubber was expected to improve the problematic soil sample in terms of their strength properties. The type of collected soil samples was coarse-grained clayey sand, which was classified as poorly graded sand. The sample was found to be unsuitable for construction purposes due to its poorly graded soil properties, whereby the soil was lacking in terms of interlocking capabilities between the particles. Besides, clayey sand, as well as poorly graded soil have higher compressibility and permeability compared to well-graded soil. Based on the tested results of crumb tyre rubber -soil sample mixtures, the following conclusions could be drawn. The addition of 0%, 5%, 10% and 15% of crumb rubber tyre to the soil samples showed the increasing trend in the OMC of up to 7% and decreased afterwards, while MDD of the modified soil remained moderately declined. This was due to the lightweight properties of the crumb tyre rubber that filled the void between the soil particles.

By referring to the California bearing ratio test, the graph of CBR value versus percentage addition of crumb tyre rubber indicated that the addition of the crumb tyre rubber tended to increase the CBR value, as well as cause the strength of the soil to increase. However, as the CBR value increased up to 10% of the crumb tyre rubber added to the soil, and further addition until 15% of the crumb rubber tyre showed a downward trend in the CBR value. It could be concluded that the optimum percentage usage of crumb rubber tyre added to the soil sample for soil stabiliser purposes was 10%. Importantly, the CBR value for all the mixtures fulfilled the minimum PWD‘s requirement (JKR/SPJ/2014) of 5% CBR value.

For further investigations, more experiments and testing could be carried out to determine the efficacy of the crumb tyre rubber and soil mixture, such as the pycnometer test, shrinkage limit test, oedometer test, direct shear test, etc., besides using other stabilising agents for the mixing materials.

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