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One Dimensional Compressibility Characteristics of Clay Stabilised with Cement-Rubber Chips

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ABSTRACT

Pre-construction treatment of soft and weak deposits is necessary to ensure safety and stability of the building or infrastructure. A common treatment of such soft soils is the stabilization method, with cement and/ or lime addition to the soil to form stabilized column or platforms through mixing. This paper focuses on the 1-D compressibility characteristics of kaolin as base clay, admixed with cement as the binder and rubberchips as an additive. This approach in engineering application is also aimed at reducing the huge stockpile of the waste tyres and its potential impact on the environment. In the study, cylindrical stabilized clay specimens were prepared with various rubberchips contents and cement, and then aged for 28 days before being tested in an automated one-dimensional compressibility apparatus (i.e. Geocomp LoadTrac-II). Analysis was carried out by relating the effects of 0, 2 or 4 % cement as well as 0, 5, 10 and 15 % rubberchips addition to the base clay. The compressibility was found to decrease significantly with small quantities of cement-rubberchips addition, though the main contributor of strength came from the cement. Also, comparison of the gradient of the reloading curves for stress levels less than the preconsolidation stress and also beyond that stress is presented. The prediction of the yield stress or settlement with higher or lower cement or rubberchips content was also analyzed. Overall, the cement-rubberchips proved to effectively increase the1-D stiffness and therefore reduce the settlements.

Keywords: *kaolin, cement, rubberchips, stabilized clays, compressibility.*

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1.0 INTRODUCTION

Globally, there are in excess of 1 billion tyres produced yearly, valued at more than USD 130 billion. These tyres, when they reach end-of-life, pose a global public health and solid waste management problem. Across Europe and United States the majority are burnt for fuel or used in roads and similar low-end applications. In Asia, end-of-life tyres (ELTs) are routinely disposed of into landfills or in an irresponsible manner that has a negative impact on the health and the environment of the surrounding communities [1].

More than 14 million of ELTs generated per year in Malaysia [2]. Although this figure is much lower than many developed countries, it is increasing year by year. Hence steps must be taken to reduced these scrap tyres that is imposing a threat to the community and country (eg. potential environment threat, fire hazards and ground breeding, consume landfill space and breeding ground for mosquitoes [3].

In recent years, there has been a growing emphasis on using industrial by-products and scrap materials in construction. Much research has been done to find solution to meet the challenge of tyre disposal problem; (i) waste tyres for lightweight construction material and sorptive drainage medium [4], (ii) in highway construction as aggregates replacement [5], (iii) making rubberized concretes [6-7]. The primary objective of the research describe here is to evaluate the compressibility of the reuse of rubberchips added to cement as an additives to the stabilised soil.

Method of stabilisation by mixing soft clay with stabilising agents or binders have been well established to improve engineering properties of the ground which results in improved bearing capacity and reduced settlements under imposed loads [8]. There are many choices and different properties of binders, namely cement, lime and industrial waste products such as blast furnace slag [9].

Hence, in this study cement proportions of 2 % and 4 % were mixed with rubberchips to stabilise the soil as a new feasible way to reduce the amount of cement used by examining the suitability and effectiveness of rubberchips as an additives in soft clay. Rubberchips will act as a flexible cushion to reduce the displacement of permanent structure and thus provides resistance against the development of cracks during deformation.

In this paper, one-dimensional consolidation tests on cement-rubberchips kaolin were measured. Apart from getting the general data on compressibility behavior of cement-rubberchips kaolin, the aim of the tests was to explore what the compressibility parameter, particularly yield stress and the prediction of the yield stress or settlement with higher or lower cement or rubberchips content.

Preliminary work has been conducted to explore the possibilities of using cement-rubberchips as an additive for kaolin, which acts as base clay with controlled properties. The combined admixture was intended to both reduce cost as well as to promote a more environmental-friendly and sustainable stabilising additive material.

2.0 MATERIALS

2.1 Kaolin

Kaolin was used in this project which formed the base clay having controlled homogeneous properties. It was used to ensure that the moisture content and density were controlled as it has a consistent size range. It is whitish in colour, soft and fine grained. The kaolin used was obtained from Kaolin Malaysia Sdn. Bhd. The particle size distribution of kaolin used is shown in Figure 1. Its uniformity coefficient, C_u is 2 and coefficient of gradation, C_c is 0.96.

2.2 Rubber chips (RC)

Rubber chips used in this study were retrieved from discarded used truck tyres by crushing and removal of the textiles and metal fibers. The rubber chips sizes are between 2 to 5 mm in average (refer to Figure 1). It was obtained from Yong Fong Rubber Industries Sdn. Bhd., Malaysia which produces reclaimed rubber such as rubber powder, rubber chips and rubber shreds. Rubber chips are incompressible elastic material, which Poisson's ratio is 0.5 and elastic modulus is about 4 to 6 MPa (average at 0 % to 15 % strains) [10]. Rubber chips were chosen in this study because it is the cheapest rubber waste compared to other reclaimed rubbers (i.e. rubber powder is RM 1/kg, rubber chips is RM 0.15/kg and rubber shreds is RM 0.90/kg).

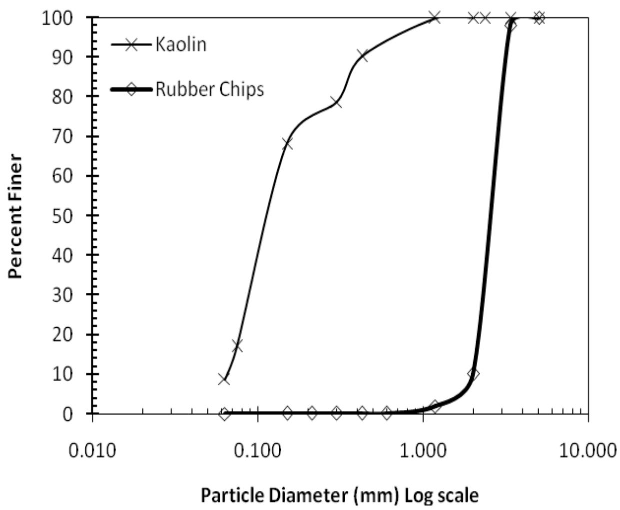

Figure 1. Grain size distribution of kaolin and rubber chips

2.3 Ordinary Portland cement

Ordinary Portland cement is a widely used stabiliser whether on its own or admixed with other additives [11]. The cement was first oven-dried at 105° for 24 hours before being stored in airtight containers to maintain the consistency of cement used in the preparation of specimens.

3.0 EXPERIMENTAL METHODS

3.1 Specimen preparation

The test specimens were prepared by varying the proportion of ordinary Portland cement and then a known proportion of rubberchips were added to kaolin paste of known water content (i.e. w = 50 %). Analysis was carried out for geotechnical properties by relating the effects of 0, 2 and 4 % cement and 0, 5, 10 and 15 % rubberchips additions, and after a 28 days curing period. These aforementioned percentages of additives were calculated based on dry mass of the kaolin.

The mixture was mixed thoroughly in a mechanical mixer and then compacted in the oedometer ring of 75 mm in diameter and 20 mm in height. A purpose-made tool was used to compact the mixture in three layers, each layer being tamped by hand in a consistent manner of fifty blows each [12]. The ends of the specimen were trimmed flat and the ring installed between the cell base and top cap. Then the specimen was left to cure for 28 days prior to testing.

3.2 One-dimensional consolidation test

In this test, a fully automated oedometer is used to run the consolidation test for the cement-stabilized soft clay. The manufactured name of this equipment is Geocomp LoadTrac-II (by Geocomp Corporation). The soil specimen (20 mm x 75 mm diameter) complying with the standards BS 1377 (1990) [13] is placed inside a metal ring with two porous stones, one at the top of the specimen and another at the bottom. The load on the specimen was applied and compression was measured by the imbedded control system. The specimen was kept fully submerged in water during the test. Every load increment will automatically go to the next load on the sample reaching its secondary compression stage. Each successive stress was doubled the previous load. Thus doubling the pressure on the specimen and the compression measurement continued.

Compressibility properties of twelve specimens were determined from the incremental loading one-dimensional consolidation test. The vertical stress levels applied during the consolidation were 12.5 kPa, 25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa. During all these tests drainage was permitted from top and bottom of the specimen.

3.3 Compression Index (C_c), Recompression Index (C_r), Yield Stress (σ_y') and Plastic Strain (ε_{pl})

The test results may be expressed in a number of ways but in this study, four useful compressibility parameters are compression index (C_c), recompression index (C_r), yield stress ($\sigma_y^{'}$) and plastic strain (ε_{pl}).

The compression index, C_c is an indication of compressibility of any soil. The e-log σ' curves obtained were bilinear, with the flatter portion corresponding to the reconsolidation at lower stress levels and the steeper portion corresponding to virgin consolidation at stress levels higher than pre-consolidation stress. The e-log σ' curve is used to derive the C_c and C_r and the maximum previous consolidation pressure as shown in Figure 2. The compression and the recompression indices are the slopes of the two portions of the curve. To calculate these parameters, two points are selected along a linear section of each portion of the curve. The two points possess void ratios e_1 and e_2, and stresses σ_1' and σ_2', respectively, are selected so that $e_1 > e_2$ and $\sigma_2' > \sigma_1'$. Compression and recompression index are then expressed as:

$$C_c \text{ or } C_r = \frac{e_1 - e_2}{\log \sigma_2' - \log \sigma_1'} \quad (1)$$

The yield stress, σ_y' represents the highest vertical effective stress that the soil has ever experienced. According to Terzaghi et al. (1996), the σ_y', at which major structure changes including the breakdown of inter-particles bond and inter-particles displacement begin to occur, is one of the most important properties of soft clays. It defines the boundary between stiff and soft deformation response of a soil towards loading. The plastic strain (ε_{pl}) shows the plasticity of the soil after compression as compare to the initial height, H_o of the soil specimen.

$$\varepsilon_{pl} = \frac{\Delta H}{H_o} \quad (2)$$

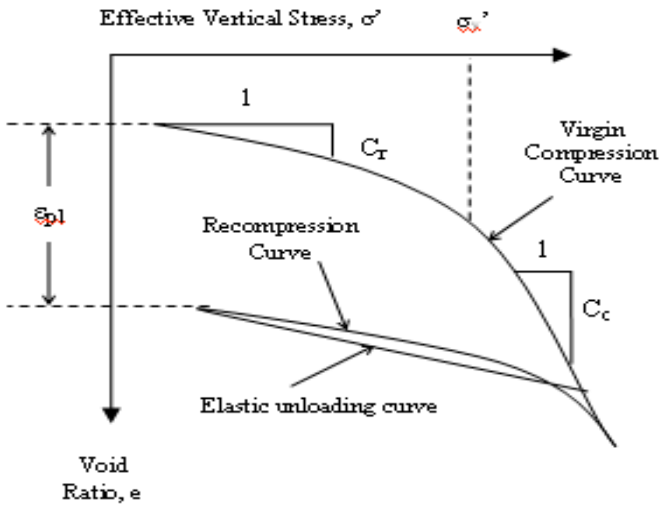

Figure 2. Typical e-log σ' curve

The elastic unloading curve or also known as the swelling line is a line where unloading of load on the soil specimen. While the recompression curve is the reloading of effective vertical stress on the soil after it was unloaded. This recompression curve will be taken as C_r for analysis because C_r value is not taken at the beginning of the consolidation curve. It is because in the very early stages of the test, small negative vertical stresses were recorded. This might not give the exact C_r value for the test. Both the recompression curve and the elastic unloading curve falls very near to one another and can be considered the same line. Hence, C_r was calculated using the elastic unloading curve (or the rebound line).

4.0 EXPERIMENTAL RESULTS AND DISCUSSIONS

Each specimen was named using acronyms name, e.g. K0c5R whereby K is abbreviation for kaolin, 0c represent 0 % cement and 5R represent 5 % rubber chips.

4.1 Compressibility specimens with different rubber chips content

For the purpose of comparison, compression characteristics will mainly be presented in terms of vertical strain rather than void ratio. The results of mixing cement and rubber chips in kaolin were shown in Figures 3, 4, and 5. These figures show the compression curves from the cement-rubber chips stabilized kaolin with 0 % cement, 2 % cement and 4 % cement respectively.

As expected, the gradient of virgin consolidation curve (or post-yield) line changes when the rate of stiffness improved, whereby 0R gives a steeper post-yield gradient, followed by 5R, 10R and 15R (Figure 3). This shows that when rubber chips were added to kaolin, the specimen became stiffer because rubber chips will transform the soil into a semi-granular material just like sandy clay and also acts as a flexible cushion to reduce the settlement of permanent. As mentioned by [14], tyre rubber is used as light-weight aggregate in concrete. It proves that in this study, rubber chips acts more like filler or a light-weight semi-granular material for the stabilised soils.

Small amount of rubber chips (i.e. 5 and 10 % rubber chips) did not contribute much to stiffness improvement of the soil. However, when adding more rubber chips (i.e. in excess of 15 % rubber chips) is able to increase the stiffness of the soil compared to specimen without rubber chips. Generally, when rubber chips were added to kaolin, a significant improvement in reduced settlement was seen.

The compression curves in Figure 3 were in fairly good arrangement compare to Figures 4 and 5 due to the effect of cementation that had a major effect on the soil behavior than the effect given by the rubber chips.

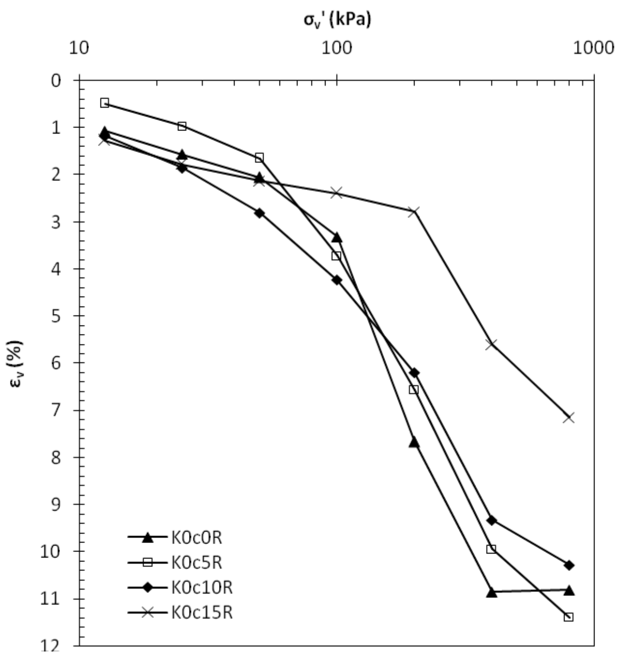

Figure 3. Compression curve for 0c

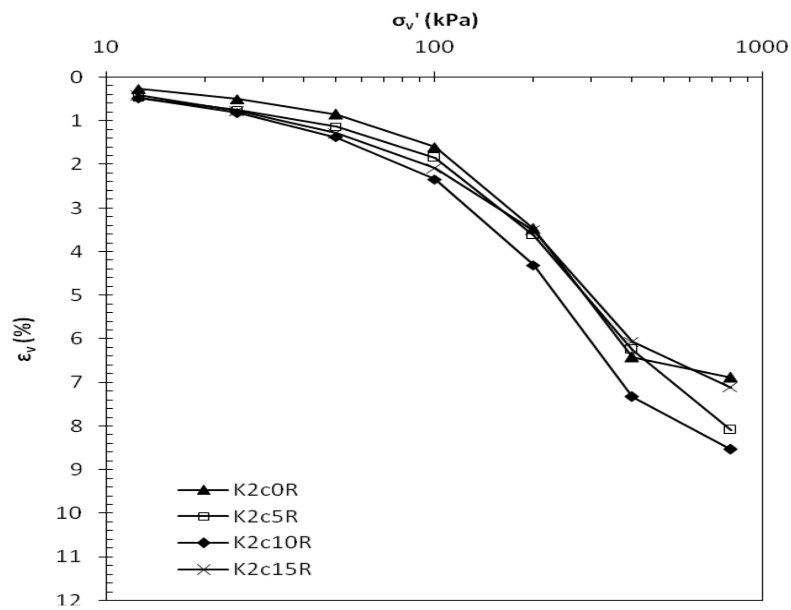

Figure 4. Compression curve for 2c

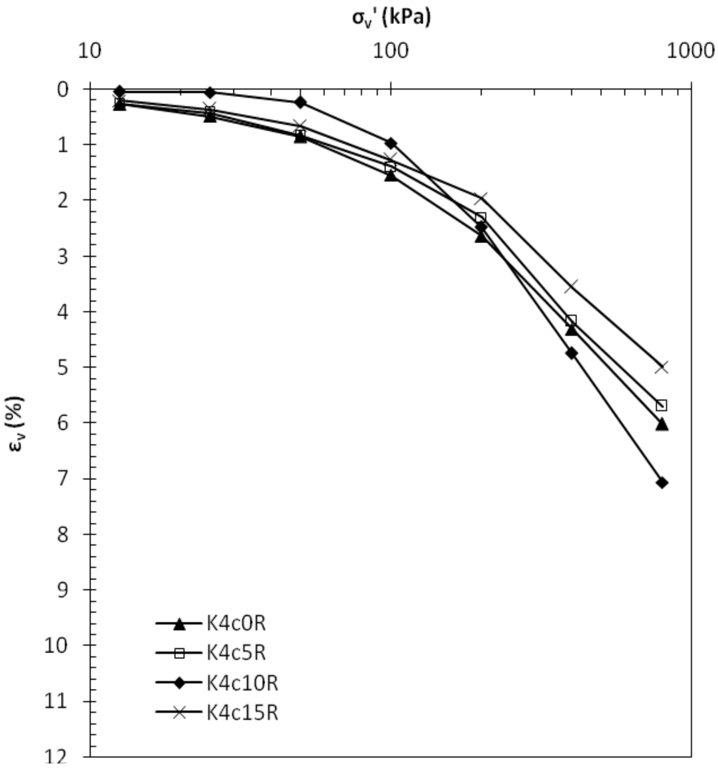

Figure 5. Compression curve for 4c

The effect of cementation can be quantified in terms of a vertical yield stress as illustrated in Figure 6. The yield stress has been determined by finding the intersection of the virgin compression line (post yield) and an initial compression line (pre-yield) whose slope has been taken to equal the average slope of an unloading/ reloading line. Yield stresses were determined similarly for all specimens as in Table 1. This method of determining the yield stress was adapted from [15].

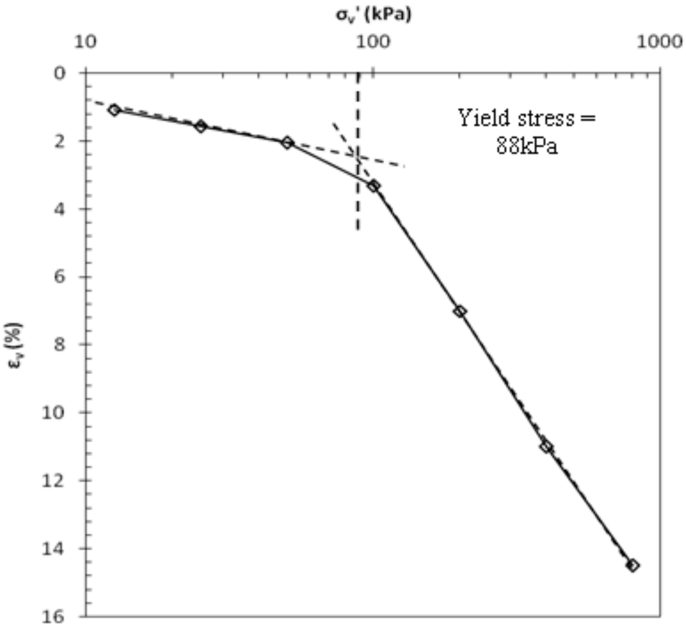

Figure 6. Illustration of effective vertical stress determination

A pre-consolidation pressure is often sought in such tests; that is the pressure at which the stiffness of the soil in the oedometer falls rapidly, and the slope of the υ: log σ'_v curve shows a sudden change [16]. It is clear that this can be thought of as a yield point (yield stress) for the soil. For stresses below the pre-consolidation pressure, σ'_{vc}, the response in the oedometer test is stiff and essentially 'elastic'.

The mixing percentage of cement content in the kaolin shows that when cement content increased, the compressibility of soil will decreased. So the addition of cement decreased the settlement of cement stabilized kaolin. This also shows that the untreated soil settled more than cement stabilized soil.

The tests are summarized in Table 1 for all specimens as obtained from the oedometer test, where w_o = initial water content, σ_y' = effective yield stress and ε_{pl} = plastic strain.

Table 1. Summary of test carried out in the oedometer for all specimens:

Specimen	**w_o (%)**	**σ_y' (kPa)**	**ε_{pl}**
K0c0R	47.92	85	0.093
K2c0R	48.07	97	0.058
K4c0R	46.43	120	0.041
K0c5R	45.12	75	0.099
K2c5R	48.01	120	0.057
K4c5R	44.57	123	0.040
K0c10R	44.15	100	0.083
K2c10R	43.96	107	0.065
K4c10R	43.19	99	0.052
K0c15R	42.31	200	0.053
K2c15R	42.23	130	0.049
K4c15R	41.82	135	0.033

As seen in Table 1, the yield stress for specimens increased when the cement content increased for 0R and 5R specimen. However, when more rubberchips were added

(i.e. 10R and 15R), a decline in yield stress was observed although the cement content increased. For the same amount of cement, yield stress increases when rubberchips increased. K0c15R gives the highest yield stress as compared to all the other specimens.
The increased of yield stress was due to the effect of structuration (existing of cementation bond) of treated clay particles. This implies that due to the effect of structuration, the volumetric compressibility of the treated specimens was very small and the stiffness was very high.

According to [17], the σ_y', defines the boundary between stiff and soft deformation response of a soil towards loading. Hence, when the cement stabilized soil is stiffer due to cement content of 2 % and 4 %, it will need a higher yield stress to begin an inter-particles displacement. This is due to the cementation that takes place after 28 days would have made the bonding between the soil particles, cement and rubberchips become stiffer.

While for the plastic strain of the specimens, it became less plastic as more cement and rubberchips were added. The plastic strains, ε_{pl} for all the specimens were calculated from the compression curve with the rebound line from Figures 3, 4 and 5 as stated in equation (2).

Rubberchips are highly compressible because of their high porosity and high rubber content. A mass of rubberchips would compress when a load is applied, primarily due to two mechanisms: 1. Bending and reorientation of chips into more compact packing arrangement, 2. Compression of the individual chips under stress [5].

4.2 Compressibility specimens with different cement content

The result from Figures 7, 8, 9 and 10 indicate that cement addition decrease the compressibility characteristics of the treated soils with different rubberchips content. An obvious pattern can be seen in all the figures whereby the rate of gradient change is equivalent to the improvement of stiffness. A reduction in the slope of the virgin curve was obtained at all treatment levels from 0c, 2c to 4c.
This is due to cation exchange reaction, an increase in the flocculation and aggregation causes a chemically induced preconsolidation effect which increases the vertical effective yield stress and reduces the compressibility characteristics [18]. Hence, cement is the more dominant factor in cement-rubberchips specimen.

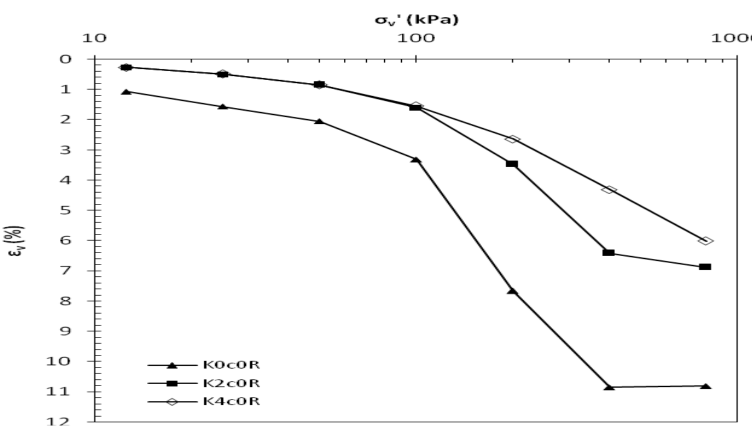

Figure 7. Compression curve for 0R

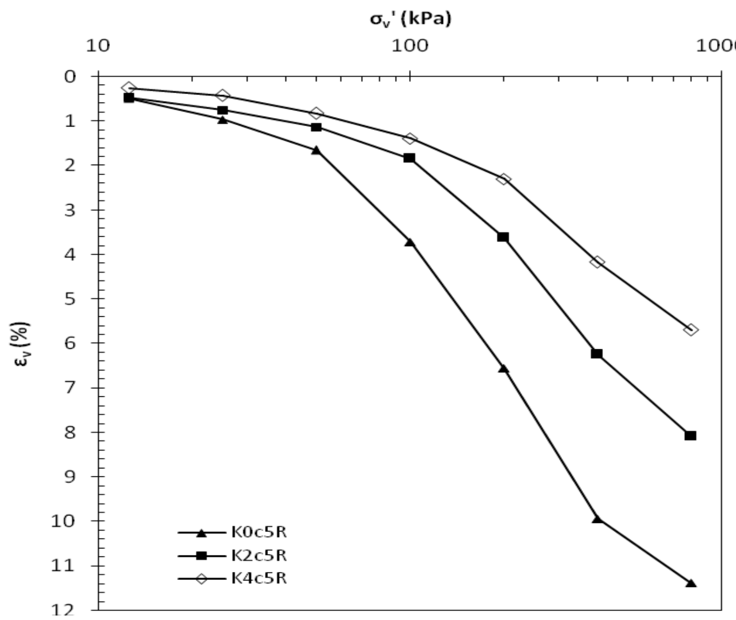

Figure 8. Compression curve for 5R

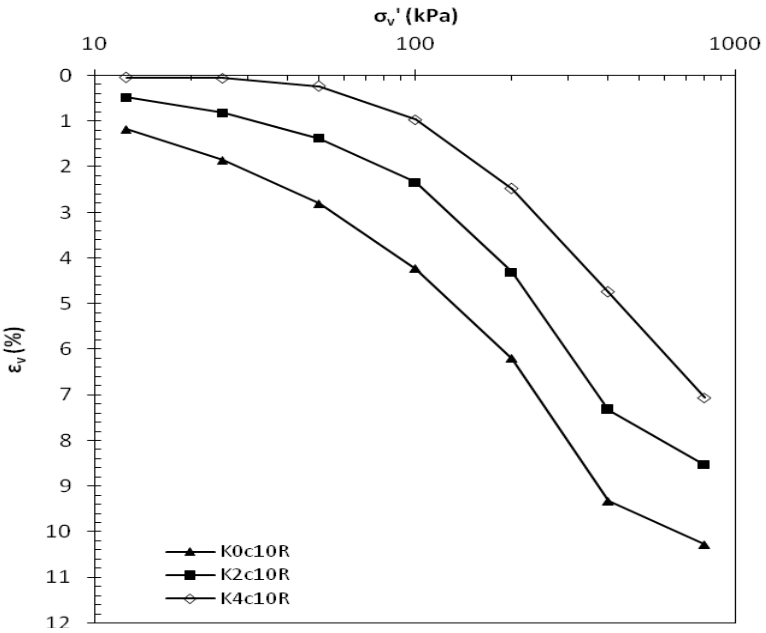

Figure 9. Compression curve for 10R

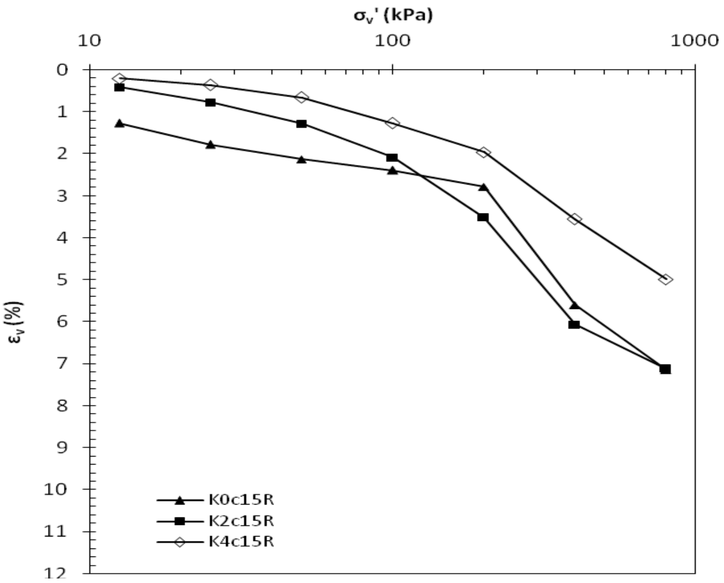

Figure 10. Compression curve for 15R

Figure 11 shows an increase in the vertical effective yield stress with an increase in the percent of cement-rubbber chips. Although the increment of yield stress is not too obvious with cement only specimen (0R), hence it can be concluded that 2 % and 4 % cement acts more of a binder than affecting the stiffness of cement-rubber chips. Also, a plateau of yield stress is observed for 2 % and 4 % cement for all the specimens. This indicates that 2 % cement is sufficient to increase the stiffness of the soil. [18] also did a similar test using expansive clay treated with lime and fly ash. The result shows an increase in the vertical effective yield stress with an increased of both lime and fly ash.

A decrease in yield stress was observed for specimen 15R when more cement was added. However K0c15R gives the highest yield stress value in this study although it decreases when 2 % cement was added. It can be concluded that when more rubber chips were added (i.e. 15R), the specimen will turned into a granular material [14] giving the soil sufficient stiffness than from the effect of cementation, which do not much effect the stiffness of stabilised soils.

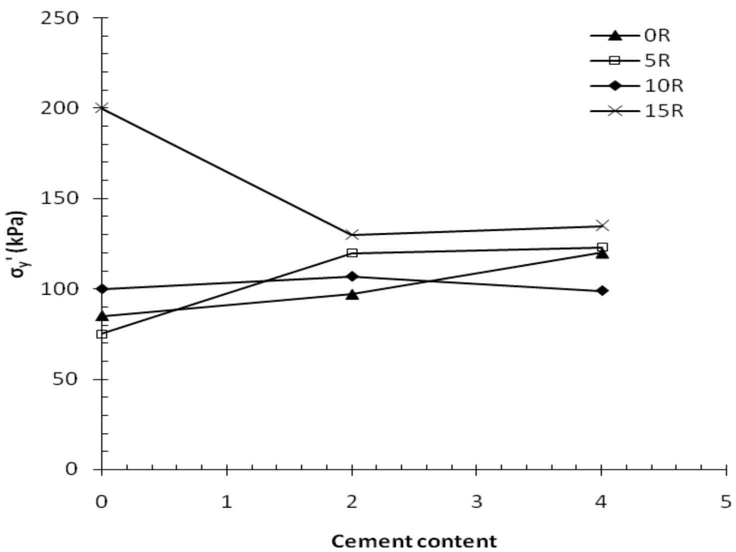

Figure 11. Effect of cement-rubber chips on the vertical effective yield stress

4.3 Compression Index (C_c) and Recompression Index (C_r) for different cement-rubber chips content

In Figure 12, the compression and rebound indices (C_c and C_r) obtained from the one-dimensional consolidation test data were plotted against percent of cement-rubber chips. The figure shows a dramatic decrease in C_c and C_r with an increase in the percent of cement and rubber chip respectively. This indicates the increased tendency of soils treated with cement-rubber chips to resist compression and expansion. Table 2 shows the compression and rebound indices (C_c and C_r) for all the specimens tested.

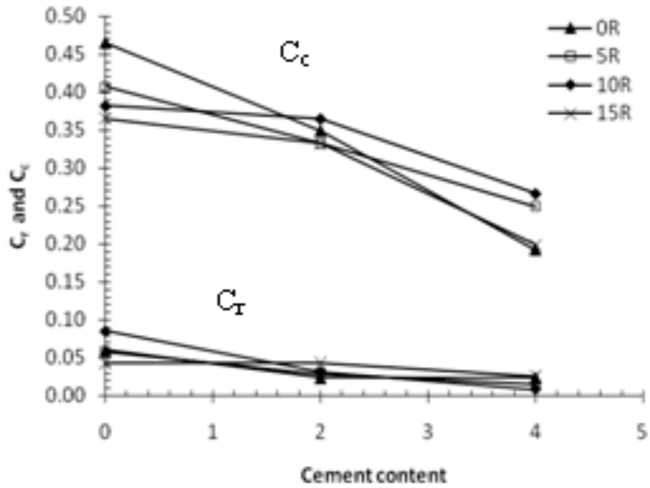

Figure 12. Effect of cement-rubber chips on the compression and rebound indices C_c and C_r

Table 2. Summary of C_r and C_c for all specimens

Specimen	C_r	C_c
K0c0R	0.060	0.465
K2c0R	0.024	0.349
K4c0R	0.024	0.192
K0c5R	0.058	0.407
K2c5R	0.029	0.332
K4c5R	0.015	0.249
K0c10R	0.085	0.382
K2c10R	0.031	0.365
K4c10R	0.008	0.266
K0c15R	0.043	0.365
K2c15R	0.043	0.332
K4c15R	0.025	0.199

5.0 CONCLUSION

This study demonstrates the influence of cement and rubber chips on the compressibility characteristics of kaolin clay. The main conclusions from this work are as follows:

1. The addition of additives and binder results in an increase in the vertical effective yield stress and a decrease in the compressibility characteristics of the treated soils.

2. The use of rubber chips with small amount of cement produces higher vertical effective yield stress; lowers the slope of the virgin curve and reduced in C_c and C_r.

3. Small amount of rubber chips did not contribute much to stiffness improvement of the soil but adding more rubber chips (i.e. until 15 % rubber chips) is able to increase the stiffness of the soil compared to specimen without rubber chips. Hence, rubber chips will transform the soil into a semi-granular material just like sandy clay.

4. Cement is the dominant factor for stiffness improvement and reduced settlement for 0R, 5R and 10R.

This study has shown that treatment of soils using cement-rubber chips can be used effectively in the stabilization of problematic soils. In short, this innovative material is able to make use of an industrial waste, economical and environment friendly.

6.0 ACKNOWLEDGEMENT

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