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SUSTAINABLE STRENGTH IMPROVEMENT OF SOFT CLAY STABILIZED WITH TWO SIZES OF RECYCLED ADDITIVE

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ABSTRACT: High amounts of ceramic waste is accumulated every year in the disposal and construction sites due to the rejection of all smashed, cracked, and broken tiles. The usage of recycled ceramic crushed tiles (RCT) in improving soft soil is considered an environmentally-friendly, economical and sustainable solution. Soft soils are characterized as problematic soils that are always associated with weak performance when loaded. It is a common practice to excavate, transport and dispose this kind of soil into landfills and replace it with a soil that meets the engineering requirements. Due to shortage of space in landfills and the high costs involved in this processes, soft soils are always treated at construction sites. In this study, two sizes of RCT (0.3 and 1.18 mm) are used to improve the physical and mechanical properties of soft soil. The size and percentage of RCT are investigated and its influence on unconfined compressive strength (UCS) and compaction is evaluated. Microstructural tests included scanning electron microscopic (SEM) and energy dispersive X-ray spectroscopy (EDS) were also conducted on samples treated with RCT. Noticeable increment in both density and unconfined compressive strength was achieved. The maximum dry density increased from 1.59 Mg/m^3 to 1.82 Mg/m^3 and 1.77 Mg/m^3 at the addition of 40% 1.18 mm and 0.3 mm RCT, respectively. Whereas the unconfined compressive strength increased from 50 kPa to 250 kPa and 225 kPa at 10% addition of 1.18 mm RCT and 40% 0.3 mm RCT, respectively. The optimum value of RCT to treat soft clay was found to be 10% and 40% for 1.18 mm and 0.3 mm RCT, respectively. The remarkable improvement in the strength of soil is due to the development of cementation compounds that acts as a binder between the RCT and soil particles. This study would help in reducing the impacts created by disposing of both problematic soil and waste tiles. Besides, cement is the most traditional material used to stabilize soil. This research would contribute to reducing the CO_2 produced during the production of cement.

Keywords: Soft Soil, Recycled Crushed Tiles, Soil Stabilization, UCS, Sustainability

1. INTRODUCTION

The fast growth of economy and population in developing and developed nations resulted in depleting the natural existing resources. The shortage of budgets and quality lands impelled researchers, engineers and land-planners to find effective methods to improve coastal soft soils. Besides, transportation projects that involve highways, railways and pavements usually pass through soft soils that, in most cases, need to be replaced. Although the construction on soft soils has been increasingly necessary, in tropical regions, it is still very low. Many traditional and innovative methods were implemented to stabilize soft soils in order to have the minimum requirements for construction [1].

Soil stabilization is an alteration of the physical and engineering characteristics of soil to attain suitable predetermined values for performance. Soil stabilization is performed using various methods and additives that vary extensively in its effect on the soil properties [2]. Soft soil is improved mechanically by compaction (e.g. [3]), chemically using chemical additives (e.g. [4]), biologically by means of bacteria (e.g. [5]), electrically by applying current into the soil, and a combination of all aforementioned methods. Chemical additives are the most used among all due to its fast enhancement to the physical and engineering properties of soil. It can be categorized into traditional and non-traditional soil additives [6]. Traditional additives can be in the form of chemical additives (e.g. [7]), fly ash (e.g. [8]), and bituminous materials (e.g. [9]). While enzymes, polymers, silicates, ions, waste materials, and acids are examples of non-traditional additives (e.g. [10].

Recently, utilization of waste materials in soft soil stabilization is given global attention in order to minimize the environmental problems and to achieve sustainability. The high costs spent in stabilizing soils using chemicals or other additives were the reason to use waste materials in soil stabilization. Employing waste materials in geotechnical applications have been a great concern of various authors [11], [12]. Meanwhile, chemical additives are usually mixed with waste materials in order to reduce the amount of the costly chemical stabilizers. In some cases and due to the environmental negative impact created by wastes materials, it is used alone to improve the physical and engineering properties of soft soils [13], [14]. The amount of waste especially that generated by construction is increasing every year. Stabilizing soft soil using construction waste would contribute to reduce the amount of waste and preserve natural resources. Besides, the common chemical-based stabilizers have created several environmental problems. Chemical-based soil stabilization requires high costs and advanced instrumentation for the application at the site [15]. In this paper, the waste produced in ceramic tiles factories and construction sites is recycled to stabilize soft clay. It is estimated that approximately 7 to 30% of the total production of the ceramic tile factories end up as a waste [16] [17]. Additionally, water is added during the production process and used during cutting the tiles, thus the waste produced is a mud-like material. This waste is gathered in areas nearby the factory as a slurry that is exposed to the atmosphere. A lot of fine contents are contained within this mud and when water is fully dried, the fine contents of the waste will be suspended in the air. A lot of environmental problems and air pollution may be caused due to the existence of this fine contents in the atmosphere. Besides, the ceramic tile waste produced in construction sites is usually disposed of legally or illegally in landfills. This dumped waste may affect the soil's fertility, consume spaces, and destroy the vegetation at the cumulating area [18].

Soft soils are found as a foundation support for structures, subgrade material for pavements or slope stabilization in geotechnical applications. Soft clay is very weak in nature and its performance under structures is poor [19]. It is usually weak and its properties are poor as a result of the high organic matter and high moisture content. Moreover, it is also associated with low permeability and uncertainty of performance [20]. The liquid limit of soft clay is usually found in a value that is lower than its natural moisture content [21]. The existence of clay minerals (e.g. vermiculite and smectite) is the main reason of highly expandable potential of soft clay [22]. According to Latifi et al. [19], clayey soils generally consists of kaolinite and montmorillonite that are partially non-swellable and extremely swellable clay minerals, respectively.

By reviewing the literature, it is revealed that no much effort has been done to investigate the suitability of RCT to treat soft soils. As a result, this study is evaluating the possible uses of RCT to stabilize soft clay. The influence of different sizes and percentages of RCT on index tests, standard proctor tests, and unconfined compressive strength (UCS) test has been investigated. Besides, microstructure and chemical tests such as scanning electron microscopic (SEM) and X-ray spectroscopy (EDS) were used to assess the stabilization mechanism before and after the addition of RCT. This research contributes to utilizing RCT as a sustainable and environmental-friendly solution to soft soil problems for cleaner and greener production.

2. MATERIALS

2.1 Properties of Soft Clay

The soil used in this study is characterized as a soft soil with high fine content, plasticity, and usually found in black color [23]. The soil was obtained from a depth of one-meter depth below the ground surface from a development site at Nusajaya, Johor Bahru, Malaysia. The soil was air-dried for two weeks and grounded into smaller particles after eliminating plants and roots. The soil was sieved using 2 mm mesh and stored in air-tight containers. Fig. 1 shows the mineral composition of the soft clay at which illite, kaolinite, and quartz are the dominant minerals in the tested clay. Additionally, Table 1 illustrates all basic, mechanical and chemical compositions of the tested clay soil. According to BS 5930 [24] and based on the results obtained for liquid limit and plasticity index, the soil is classified as CLAY with intermediate plasticity (CI). The organic contents found in this soil is less than 3% which according to Wong et al. [25] proof that the soil is inorganic.

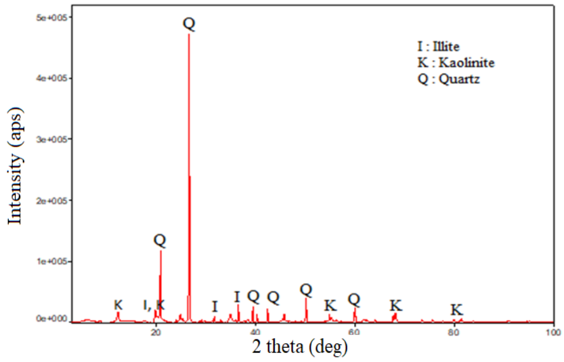

Fig.1 The mineralogical components of soft clay

Table 1 Basic and chemical properties of the soft clay

Properties	Unit	Average Value
Sand	(%)	33
Silt	(%)	31.1
Clay	(%)	30.9
Specific gravity		2.52
Liquid limit	(%)	41
Plastic limit	(%)	22
Plasticity index	(%)	19
W_{opt}	(%)	22
γ_{dmax}	kg m^{-3}	1590
UCS	kPa	50
BS classification		CI
Chemical compounds		
Al_2O_3	(%)	16.83
SiO_2	(%)	36.75
FeO	(%)	30.02
Na_2O	(%)	0.27
CaO	(%)	0.44
MgO	(%)	0.47
K_2O	(%)	8.66

2.1 Properties of Recycled Crushed Tiles

The additive used is considered as an environmental-friendly and sustainable product called recycled crushed tile (RCT). The RCT utilized was collected from dumping areas at construction sites in Johor state, Malaysia. Table 2 demonstrates all the physical and chemical properties of RCT. It is notable that ceramic tiles have considerable amounts of sodium and magnesium.

Table 2 Physical and chemical properties of RCT

Property	Unit	Value
Phase		Coarse
Diameter size	mm	0. 3 and 1.18
Color		White
Density	kg m^{-3}	2.10
Chemical compounds		
Al_2O_3	(%)	24.37
SiO_2	(%)	65.83
FeO	(%)	2.81
Na_2O	(%)	3.19
CaO	(%)	1.64
MgO	(%)	5.84
K_2O	(%)	2.33

Tiles were prepared in several steps started by cleaning and removing materials sticking to its surface. Besides, for fitting into the crushing machine, the ceramic tiles were first crushed using hammer into smaller pieces. Then, the crushing machine was used to further crush the tiles into 5 mm particle size. For obtaining fine contents, Los Angles abrasion machine was used to crush the tiles into a mixture of fine and coarse sizes by rotating the crushed tiles for 12 hours. Finally, the mechanical shaker was used to sieve the mixture to obtain the required sizes of tiles. The sizes of RCT used in this study were 0.30 mm (Fine size) and 1.18 mm (Coarse size).

3. TESTING PROGRAM

Various mix designs of 0.3 and 1.18 mm RCT were used to conduct the compaction tests in accordance with BSI 1377: Part 4 [26]. First, the soil was sieved through 2 mm sieved and mixed thoroughly with RCT using a hand. After homogeneity of the dry mix was observed, the mixture was mixed with a predetermined amount of water. Air-tight plastic bags were used to keep the wet mixture for 24 hours to ensure better distribution of moisture within the mixture. A standard compaction mold with a standard height of 115.5 mm and an internal diameter of 105 mm was used for the compaction tests [27]. All samples of soft clay-RCT mixtures were compacted insides the compaction mold in three equal layers by dropping vertically a metal rammer (2.5 kg) from a height of 300 mm. Each layer was then subjected to 27 blows. Then, the optimum moisture contents (OMC) and the maximum dry densities (MDD) of all the mixes were determined.

A sampling of UCS started by using the predetermined values of MDD and OMC for the various mix designs of soft clay-RCT. The sieved 2 mm soft clay was oven-dried for 24 hours prior to mixing to ensure zero water content. The samples for treated and untreated soft clay were prepared using a cylindrical stainless mold with a dimension of 80 mm height and 38 mm diameter. The inner surface of the mold was lubricated before compacting the samples to prevent the samples from damaging while extruding it out of the mold. All samples were prepared using distilled water and the time of preparation did not exceed 2 minutes in order to prevent the moisture from evaporating [6]. Prior to the mixing, the proportions of RCT were determined based on the dry weight of the clay. RCT, distilled water, and soft clay were mixed using palette knives until homogeneity was observed. The mixture was divided into three layers placed inside the mold. A steel tamper was used to compact each layer 27 blows in order to achieve the desired dry unit weight [28]. The compacted samples were extruded using a hydraulic jack machine. Next, the samples were placed in plastic bottles after being trimmed and wrapped with several layers of cling film. The plastic bottles containing the UCS samples were kept inside controllable humidity chamber for different curing periods (7, 14, and 28 days). The weight of the samples was measured after the curing period and samples with more than 0.5% weight reduction were rejected. For each mixture of soft clay-RCT, a minimum of three samples was used to ensure better observation of the strength gain after the soft clay was improved. The rate of axial strain under which the samples were loaded was 2% per minute. Besides, a data acquisition unit (DAU) was automatically recording the axial deformation and the applied load. The maximum axial strain was set to 20% and the ultimate strength of the UCS samples was attained according to its peak axial stress at failure [29]. If the difference in peak axial stress was more than 10%, the sample was rejected and the test was repeated, otherwise average of three samples was taken as the UCS value [30]. The failed samples were weighted and oven dried for the purpose of determination of post-testing moisture content.

Energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopic (SEM) were the microstructural and chemical tests conducted in this study. The samples used for those tests were the same samples tested under the UCS test. Samples were oven-dried for 24 hours prior to testing in order to stop the reaction taking place between the soil and the RCT [28]. Dried samples were pulverized to a powder and two tiny samples were mounted in an aluminum holder that was coated with thin layer of platinum in order to induce conductivity. The samples were installed inside A JEOL Model JSM 6380LA scanning electron microscope (SEM) that was operating with 15 kV. The SEM testing is used to qualitatively assess the micromorphological changes of the soil fabrics providing data about its shape, size and orientation. Besides, during the imaging of the soft clay-RBT samples, the elemental compositions at the surface of the analyzed samples were determined using energy dispersive X-ray spectroscopy (EDS).

4. EXPERIMENTAL RESULTS

4.1 Compaction Test

Untreated and treated soft clay with 10, 20, 30 and 40% of 0.3 and 1.18 mm RCT undergone several compaction tests. The relationship between the optimum moisture content (OMC) and the maximum dry density (MDD) is presented in Fig. 2. It can be observed that increments of both 0.3 and 1.18 mm RCT resulted in increasing the MDD and decreasing the OMC of soft clay. The high increase in MDD can be due to the replacement of the RCT particles of higher specific gravity by the clay particles of lower specific gravity. Moreover, the attraction for water molecules was reduced and this can be attributed to the substitution of RCT particles by the soft clay particles. Thus the optimum moisture content of the mixtures was reduced with increments of RCT [31], [32]. Additionally, when comparing the size effect of RCT, the higher the size of RCT, the higher the maximum dry density (MDD) [33]. Hence, the bigger size of RCT significantly improved the dry density of soft clay. The reason for such improvement is that particles of 1.18 mm RCT were coated with the soft clay particles which resulted in bigger particles occupied larger area [34].

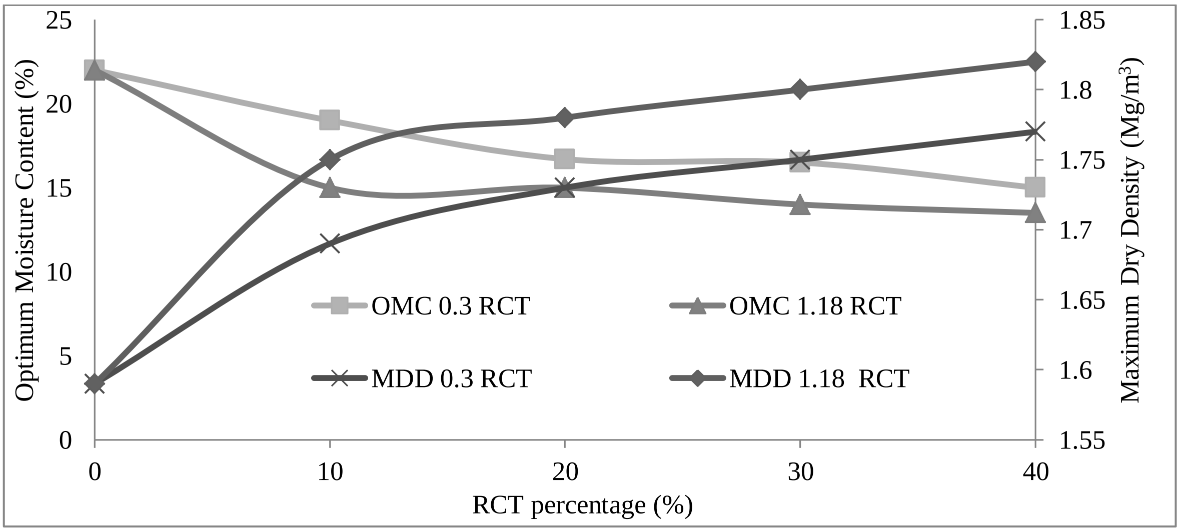

Fig.2 Compaction parameters of the soft clay-RCT mixture

4.2 Unconfined Compressive Strength (UCS)

The unconfined compressive strength (UCS) is used to assess the strength development of untreated and treated soft clay by two different sizes of recycled crushed tiles (RCT). The strength development of untreated clay and samples treated with 0.3 mm and 1.18 mm RCT at different curing periods are shown in Fig. 3 and Fig.4, respectively. It can be observed that the strength of the clay was increased from 50 kPa to approximately 250 kPa when 40% 0.3 mm RCT was added. On the other hand, when 1.18 mm RCT was added, the highest strength was attained at 10% RCT. Further increments of 1.18 mm RCT resulted in a reduction of the strength due to the large size of RCT when compared to the very fine size of the clay. Meanwhile, the strength was increased with further increments of 0.3 mm RCT and 40% RCT was found to be the optimum value. For all curing times, it was observed that 0.3 mm RCT was able to improve the strength of the clay. Moreover, the insignificant difference in strength development of 0.3 mm RCT treated samples was observed when comparing that of 14 and 28 days. In contrast, the strength was reduced during 28 days curing period for samples treated with 1.18 mm RCT.

The formation of new cementation compounds and the exchange of cations were the reason behind the increment of strength in samples treated with the fine size of RCT. The presence of sodium and magnesium in RCT contributed in forming the cementation compounds. This reduces the porosity of the treated samples. For the coarse size of RCT, the strength was dropped due to its larger size when compared to the fine particles of the clay. Therefore, no significant improvement was observed during the curing time and this confirms that it only acted as a filler material. Besides, the alkalinity of RCT was high which contributed to minimizing the chance of having a chemical reaction when RCT exceeded 10%.

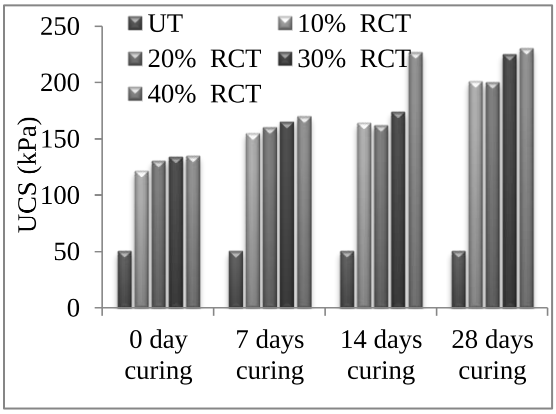

Fig.3 Unconfined compressive strength of 0.3 mm RCT stabilized soft clay

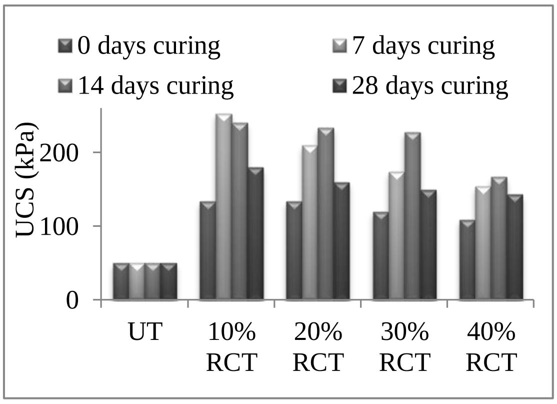

Fig.4 Unconfined compressive strength of 1.18 mm RCT stabilized soft clay.

4.3 Analysis of SEM and EDS

SEM and EDS were used to observe the changes on the surface of untreated and treated soft clay-RCT samples. The morphological changes in the surface of untreated soft clay and treated clay with optimum RCT (40% 0.3 mm RCT and 10% 1.18 mm RCT) at 14 and 28 days curing periods are shown in Fig. 5a-e. The untreated sample has a discontinuous and porous surface that can be due to the absence of the hydration compounds. Whereas, for treated samples with 0.3 mm RCT, white lumps can be observed on the surface due to the reaction between the soil particles and the RCT. This formation was responsible for the observed continuous and denser surface for the treated samples. In contrast, the samples treated with 1.18 mm RCT almost have a similar surface structure as the untreated soft clay. This shows that the large size of RCT was not able to react with the particles of soft clay. In order to understand the chemical composition on the surface of untreated and treated samples, EDS analysis was performed. Fig. 6a-c shows the EDS analysis of untreated and treated soft clay with 0.3 mm RCT and 1.18 mm RCT at 28 days curing period. The elements of Si, Al, O, and K were the main elements forming untreated soft clay. Meanwhile, samples treated with 0.3 mm RCT had high intensities of Mg, Na, Fe, O, and K while those samples treated with 1.18 mm RCT had lower intensities of the same elements. The lower intensities observed for those samples resulted in the low reaction between the large size of RCT and the clay particles. Furthermore, RCT is enriched of Si and Al which resulted in increasing the amount of these elements in the treated samples. The analysis showed that the mineral responsible for the surface changes of treated samples was aluminum magnesium silicate hydrate (A-M-S-H) [35], [36].

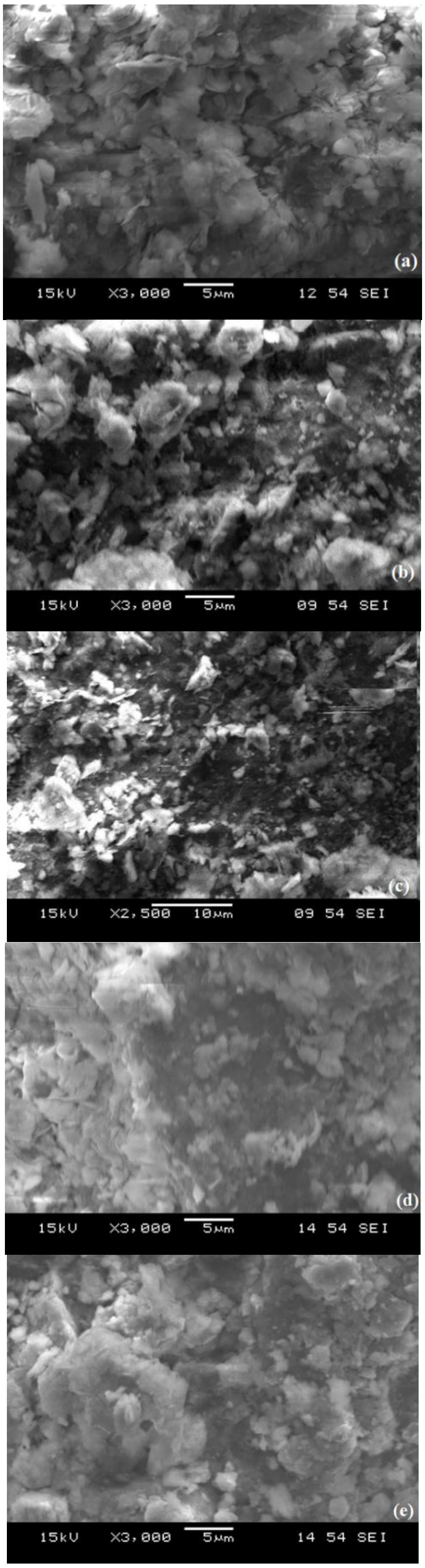

Fig. 5 SEM micrographs of untreated clay (a), soft clay stabilized with 40% 0.3 mm RCT cured 14 days (b), soft clay stabilized with 40% 0.3 mm RCT cured 28 days (c), soft clay stabilized with 30% 1.18 mm RCT cured 14 day (d), and soft clay stabilized with 30% 1.18 mm RCT cured 28 days (e)

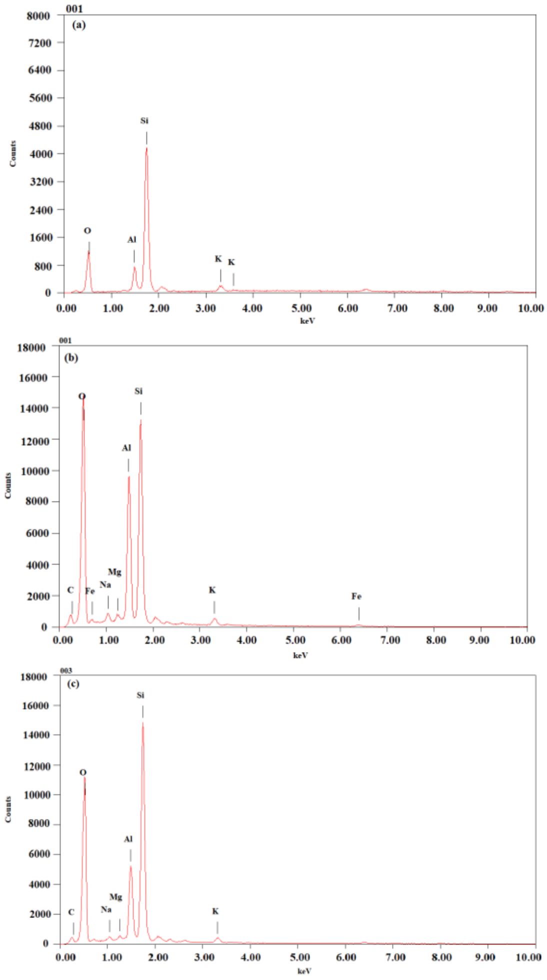

Fig.6 EDS spectra for (a) UT, (b) treated clay with 40% 0.3 mm RCT cured 28 days, and (c) treated clay with 10% 1.18 mm RCT cured 28 days

5. CONCLUSION

Laboratory tests were performed for untreated samples, treated samples with 0.3 mm RCT, and samples treated with 1.18 mm RCT. Tests were done to observe the effect of RCT on the compatibility and unconfined compressive strength of soft clay. For this purpose, the laboratory experiments included specific gravity, Atterberg limits, standard proctor tests, unconfined compressive strength, EDS and SEM were conducted on the soil. In general, the addition of RCT could improve the soft clay and some cementation compounds were formed by the reaction between RCT and soft clay particles. Therefore, permanent improvement of the compressive strength was achieved. Based on the results obtained from the tests conducted, the following conclusions can be drawn:

1. The compaction parameters were improved by the addition of both sizes of RCT.

MDD was increased and OMC was decreased with further additions of RCT.
2. The unconfined compressive strength was improved significantly when 40% and 10% of 0.3 mm and 1.18 mm RCT were added. While further additions of 1.18 mm RCT resulted in a reduction in the UCS value and this is due to the large size of RCT.
3. The results obtained from the analyzed treated samples using SEM showed some changes in the surface of the samples due to the formation of new cementation compounds.

6. ACKNOWLEDGMENTS

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