Utilization of Eco-Friendly Construction and Demolition Waste Materials in Soil Improvement

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Abstract. This study comprehensively assesses using Concrete Waste (CW) and Rubber tire Fly Ash (RFA) eco-recycled materials to enhance the mechanical characteristics of cohesive soil obtained from Al-Araby district in Mosul city/Iraq. These materials are added by 3, 6, 9% CW and 6, 12, 18, and 24% of RFA of soil dry weight and passed sieve (No.40), in addition to adding 3, 6, and 9% cement as an activator to soil-RFA mixture. Several techniques have been used, such as mercury intrusion porosimeter, X-ray diffraction, unconfined compressive strength, water retention ability, and axial sample compressibility. In addition, curing period effects on soil-soil-eco-recycled mixtures have been evaluated. Results showed that 18% RFA had been concluded to be the optimal percentage. Also, adding eco-recycled materials exhibited an alteration in soil pore structure distribution from meso to micro-meso pore size for CW and to predominantly micropore size for RFA, and modifying the treated soil compressive strength properties. At the same time, varied effect on maximum dry density has been observed between the development in CW addition and decrement in RFA, accompanied by decrement in soil compressibility and water retained ability for both eco-recycled materials. Also, a 5.5% cement activator addition to the soil-RFA mixture was the optimum cement activator percentage. The curing period tests of soil treated with (CW) and soil-18%RFA-5.5% cement activator reflected cement's continuous pozzolanic reaction ability in concrete waste additive and cement activator, respectively.

Keywords: Concrete waste; rubber fly ash; cement activator; cohesive soil.

1. INTRODUCTION

Utilizing recycled materials in soil stabilization provides alternatives from an economical, technical, and environmental point of view. In northern Iraq, Mosul city suffers from construction waste materials dumped in streets and rubble between residential buildings. These dumps come from military operations in 2016 that made tons of building debris, population growth, and the evolution of infrastructure development. Clayey cohesive soils may need to be improved in some cases by mechanical or chemical stabilizing methods through in-situ ground improvement or replacement techniques, which are sometimes costly. Therefore, using recycled waste materials, such as scrap tires/or tires ash and concrete waste materials, could be a good choice for their inexpensive cost and desired engineering properties [1,2]. Concrete materials consist of course /fine aggregate and cement paste and may contain chemical modifiers [3,4]. The waste materials could be used instead of aggregates or as pozzolanic binder components [5,6]. In this context, the rubber tires' waste materials accumulated in large quantities, causing an increasing threat to the environment [7]. Thus, recycling these non-hazardous solid wastes is necessary to eliminate the negative impact of these wastes. Tire wastes can be used as whole tires, shredded /chips, or ash powder mixed with soil. Using tire waste materials in geotechnical applications has been dealt with, especially as embankment and filling materials [8-10]. This study focuses on using construction waste materials such as concrete agglomerates and rubber tire fly ash to improve the mechanical properties of soft clayey soil extracted from Al-Araby district in the north of Mosul city/Iraq.

2. MATERIALS

2.1 The Soil

The soil used in this study was extracted from Al–Araby district in Mosul city from a depth of about 1.0 m below the ground level. Figures 1 to 3 and Table 1 show the engineering properties of the soil used in this study.

Table 1: Index engineering properties of the soil.

ASTM D4318-00 [11]		**ASTM D854-02[12]**	**Test method [6]**	**Test method [13]**	**Test Method [14]**
L.L. %	P.I. %	Gs	pH value	T.S.S %	O.C %
50	13	2.68	7.1	5.8	0.34
ASTM D422-63 [15]				Soil Classification	
Sand %		Silt %	Clay %	U.C.S	AASHTO
11.6		62	26.4	SC	(A-2-6)

T.S.S.: Total Soluble Salts, O.C: Organic Content

2.2 Concrete Waste (CW), Rubber Tire Fly Ash Waste (RFA), and Cement Materials

The percentages of CW used in this study are (3%, 6%, and 9%) by soil dry weight, with a specific gravity of 2.8-2.87, obtained from the concrete construction debris in Mosul city, cleaned and ground into small pieces by crusher mill. While 6%, 12%, 18%and 24% by soil dry weight of RFA was used in fly ash form with a specific gravity (1.17-1.21) after firing the rubber tire waste material at (700-800^{o}C). The maximum grain sizes of CW and RFA are less than 0.475mm (i.e., pass sieve No.40). Ordinary Portland cement has been used as an activator with soil-RFA mixture, with an amount of (3, 6, and 9) % of soil –RFA mixture dry weight.

3. CHARACTERIZATION TECHNIQUES

3.1 X-ray diffraction (XRD) and Thermo Gravimetric Analysis (TGA)

XRD was conducted on CNRS-CRMD (National Center for Scientific Research) IN France using a natural soil powder in order to identify its mineralogical composition using Philips Apparatus with the Kα line of copper (λCu=1.5406 Å) at 2θ:1.5- 60°C. The amounts of clay and non-clay minerals have been measured using TGA test. In this test, the lost mass of the sample is recorded under a controlled temperature ramp by Setaram TG-DTG 92-16 electro-balance apparatus operating with a heating rate of 100°C/hour under an argon atmosphere within 20-1000°C range.

3.2 Pore Size Distribution (PSD) Analysis

PSD of the natural soil and soil treated with waste materials have been tested in CNRS-CRMD using the mercury intrusion porosimeter (mip) method. The samples were immersed in liquid nitrogen gas at a temperature of (-198^{o}C); leading to freeze the sample within both its solid skeleton and the water inside its pores, followed by drying the freeze samples using vacuum pressure in sublimation equipment (lyophilisateur α 1-2 plateaux M91276/BIOBLOCK SCIENTIFIC-FRANCE). MIP was performed using a 9320 porosimeter apparatus [5].

3.3 Water Retention Curve (WRC)

Remoulded processed samples (30 mm diameter and 12 mm height) have been used and prepared by static compaction at a rate (1.27 mm/sec.) under maximum dry density (MDD) and optimum moisture content (OMC) compaction conditions. The remolded samples are oven-dried at (105±5^{o}C) for 24 hours before starting the test [16, 17]. The WRC consists of three technical parts: salt solutions, osmotic solution method, and tensometric plates [16]. The test was conducted in CNRS-CRMD.

3.4 Standard Compaction Test

The standard compaction properties (i.e., dry density-moisture content curves, Maximum Dry Density MDD, and Optimum Moisture Content OMC) were measured in the natural and processed samples according to ASTM D698-7 [18].

3.5 Uniaxial Compressive Strength Test

A uniaxial compressive strength test has been done for 100 mm diameter x 200 mm height. Cylindrical samples were prepared according to MDD and OMC standard compaction conditions [18]. The uniaxial compressive test was measured using a MATEST testing machine with 2000 kN capacities and 0.02 mm/sec loading rate [19].

3.6 Compressibility Test

The compressibility test has been carried out according to ASTM D2435-96 [20] on remolded natural and processed samples under MDD and OMC conditions.

4. CEMENT ACTIVATOR AND CURING PERIODS EFFECT

4.1 Effect of Cement Activator

The effect of cement addition (i.e., activator) has been attained on 100 mm diameter x 200 mm height cylindrical soil-RFA mixture- 3%, 6%, and 9% cement samples, which were prepared at MDD, OMC, and maximum uniaxial compressive strength conditions.

4.2 The Impact of Curing Periods

The impact of curing periods has been evaluated on 100 mm diameter x 200 mm height. Cylindrical soil-optimum RFA-optimum cement activator and soil-CW samples were prepared according to MDD and OMC conditions. The samples were covered with closed sacks, stored in a constant temperature room (20 ± 2^{o}C), and left for periods (0, 4, 7, 14, and 28 days).

5. RESULTS AND DISCUSSION

Depending on the test conditions mentioned, soil and waste materials are used. The following results were obtained: Figure 1 shows PSD of the natural soil tested by MIP method. This distribution shows three ranges of pores: (0.01 µm ≤ micro pores ≤ 1 µm), (1 µm ≤ meso pores ≤ 6 µm) and (6 µm ≤ macro pores). The pore diameter (6 micrometers) may be considered as the limit value between micro-meso pores (i.e., less than 6 µm) and macro pores (i.e., more than 6 µm). According to this result, the pore soil structure could be described as meso. Figure 2 shows two suction zones in the WRC of the natural soil: (I) the water was retained by more than 2 MPa suction capillary forces in the meso-micro pores; (II) the liquid water fills easily the macro pores by suction capillary less than 2 MPa.

Figure 3 presents the mineralogical compositions of the natural soil characterized by XRD. These compositions are (Glauconite (mica in general), Calcite ($CaCO_3$), Quartz (SiO_2), Gypsum ($CaSO_4.2H_2O$), and Bassanite ($CaSO_4.0.5H_2O$)). Also, different salt minerals have been -observed and represented by Halite (NaCl) mineral, Biotite(1M) mineral, and Portlandite ($Ca(OH)_2$). TGA shows that clay minerals and gypsum varied from (2.15-2.45 %) with Calcite minerals (21.73 ± 1.2 %).

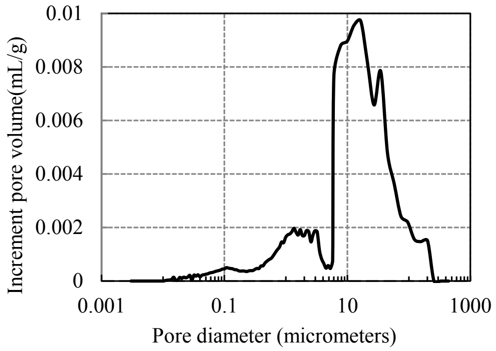


Figure 1: PSD of natural soil.

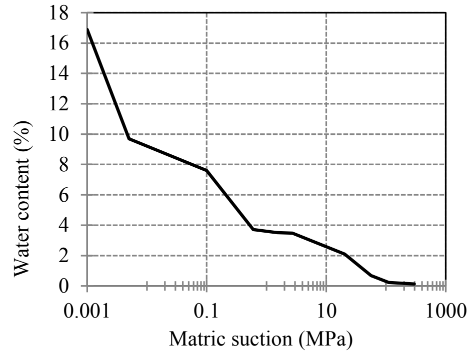


Figure 2: WRC of natural soil.

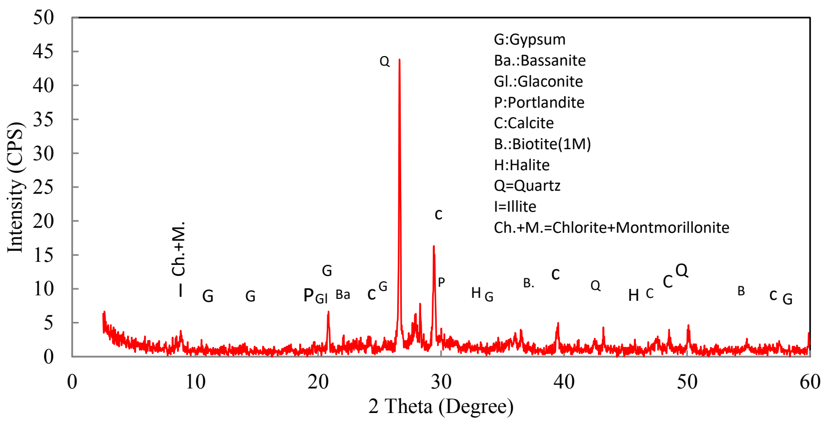


Figure 3: XRD of natural soil.

Figure 4 shows the results of the standard compaction test of the natural and soils treated with waste materials, as a continuous increase in the amount of both OMC and MDD of the soil was treated by CW and shown in Figure 4a. This could be related to the pozzolanic reaction between cement presence within CW and soil particles. In addition, CW powder fills the soil pores [17]. Figure 4b shows soil treated with RFA. A reduction in the amount of MDD by 16.4% at 18%RFA was noticed, accompanied by the increase in the amount of OMC. The decrease in MDD resulted from the low specific gravity of the RFA. At the same time, the increment in OMC could be attributed to RFA absorption of additional amount of water to redress the amount of water lost within the firing process of RFA material. Figures 5 shows the relations between the maximum compressive strength and axial deformation of the natural soil and soils treated with CW under MDD and OMC conditions. Adding CW to soil exhibits a continuous increase in the compressive strength by about 44% for (9% CW) and reduction in the axial deformation by about 59.26%, compared with the untreated soil condition.

In spite of the reduction in the treated soil, the dry density was related to RFA additions (Figure 4 b). An augmentation of maximum compressive strength values by about 91.4 % for the soil treated with (18 %) RFA was observed in Figure 6, followed by reduction in the strength because of the excessive amount of RFA. The percentage of 18 % RFA could be considered the optimal percentage of the RFA addition.

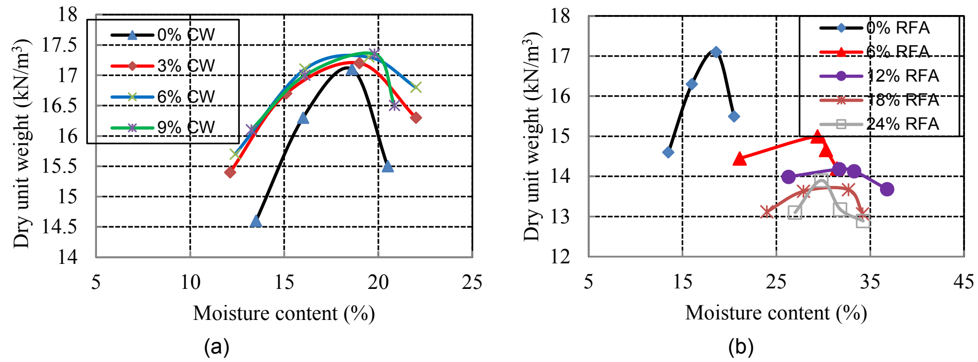


Figure 4: Compaction curves of soil treated with (a) CW, and (b) RFA.

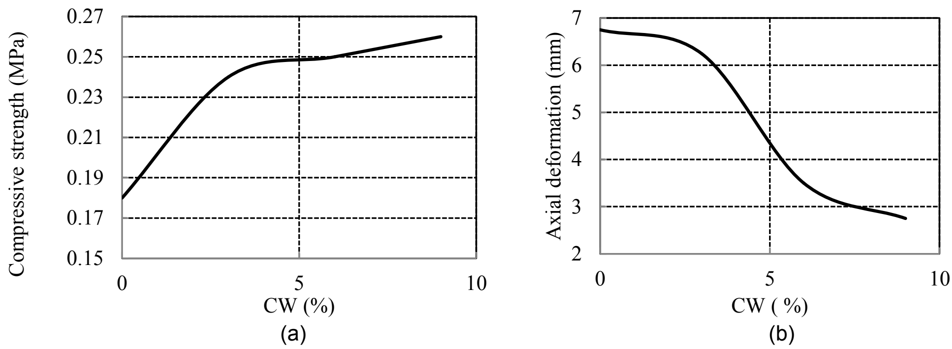


Figure 5: (a) Unconfined compressive strength, and (b) Axial deformation of soils treated with CW.

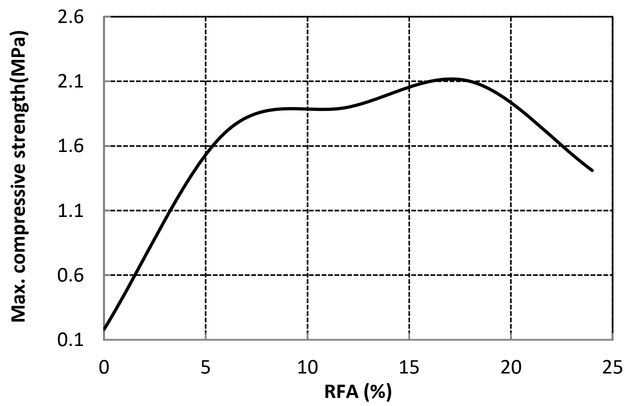
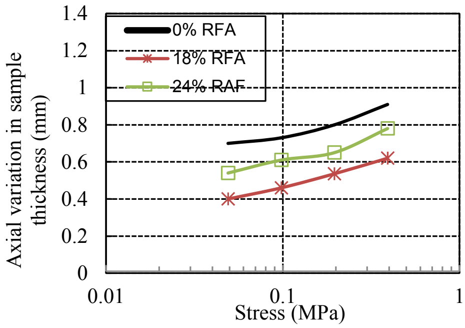


Figure 6: Unconfined compressive strength of treated and untreated soil with RFA.

Figures 7a and b show the compressibility of natural soil and soils treated with CW, and RFA respectively. In terms of applied stress-soil axial deformation, relationship under maximum compressive strength, MDD, and OMC conditions, relating to CW addition. Figure 7a shows the pozzolanic reaction of cement material within CW compositions and filling soil pores with this waste material, leading to a continuous reduction in the axial deformation rate. However, in case of RFA addition, Figure 7b shows an increase in soil samples stability treated with 18% RFA through the decrease in axial deformation. But the excessive amount of RFA represented by the percentage 24% RFA caused enlargement of the soil pores and fragmentation of soil structure. And hence the increase of the soil axial deformation.

Figure 8 shows the PSD of natural soil and soils treated with 9% CW, and 18% RFA. All the added waste materials could alter the treated soil pore distribution from predominantly macro pores toward micro-meso pores, where the addition of CW and RFA led to the decrease of the macro pores amount by 0.05021 ml/gm and 0.06561 ml/gm respectively. The increase in micro-meso pores quantity was 0.0138 ml/gm and 0.0453 ml/gm, respectively. This alteration could probably be related to the high specific surface of both CW and RFA.

The variation of the treated soil pore distribution reduced the ability of these soils to retain water within their pores and alter it to be weaker, as shown in Figure 9. This reduction could be related to the obstruction of water molecules access to soil pores because of the setting of waste materials inside pore zones. To identify the effect of cement additions as the activator of soil-18% RFA mixture, soil samples treated with 18 %RFA and (3, 6, and 9%) of cement materials were prepared in this study.



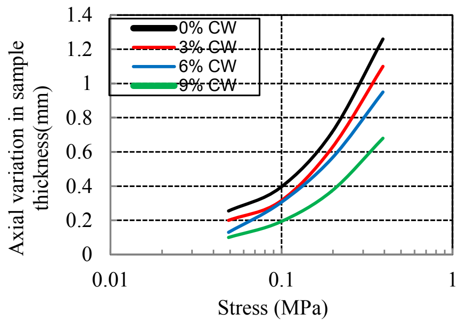


Figure 7: Axial deformation of soils treated with (a) CW, (b) RFA.

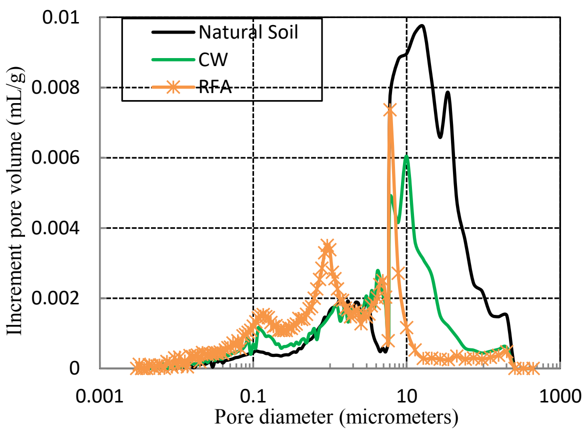


Figure 8: PSD of soils treated with waste materials.

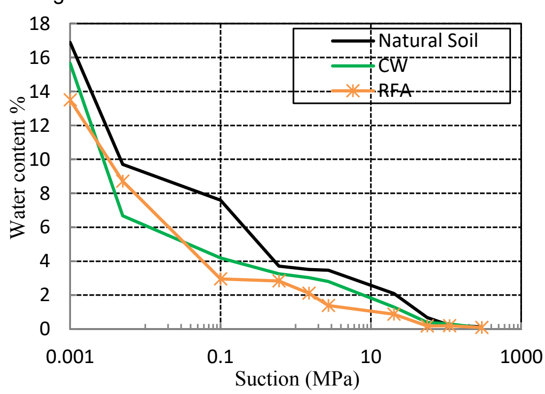


Figure 9: WRC of soils treated with waste materials.

Figure 10 shows the maximum compressive strength of soil–18 % RFA mixtures treated with various cement amounts. An improvement in the maximum compressive strength was observed by an amount of 12.8% at a cement percentage of 5.5%, followed by a reduction in the compressive strength value. It could be said that adding cement provides additional stability to the mixture structure by forming a harder gel in the treated soil structure.

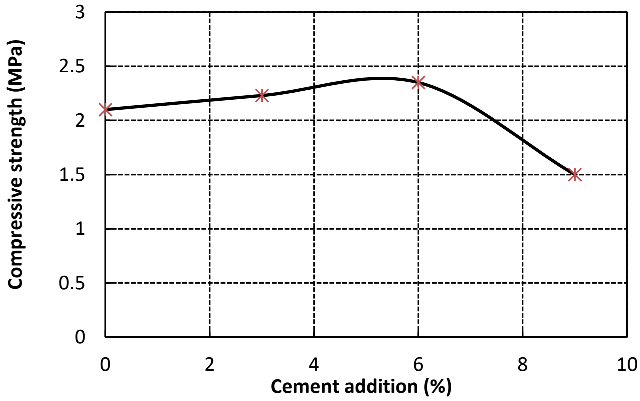


Figure 10: Compressive strength of soil -18 % RFA -cement additions.

6.1 Adding Cement Material (Activator) to Soil-18% RFA Mixture

With 5.5% cement addition, this stability reduction was observed, probably due to the uncompleted cement hydration under the limited moisture content in soil – 18% RFA mixture [17]. Here, 5.5% cement could be described as the preferred percentage for the soil-18% RFA mixture.

6.2 Compressibility of Soil-18% RFA -5.5% Cement Mixture

Figure 11 shows the compressibility test results of natural soil, soil -18% RFA mixture, and soil -18% RFA -5.5% cement mixture, prepared in this study and stored for 24 hrs. Adding of RFA material was followed by adding 5.5.% cement and hence produced a progressive, stable soil structure with lower values of the total strain variation and the compressibility (i.e., lower compressibility index (cc) while the swelling index (cs) remains the same because adding materials is considered to be optimal and not excessive to get a change in the swelling index.

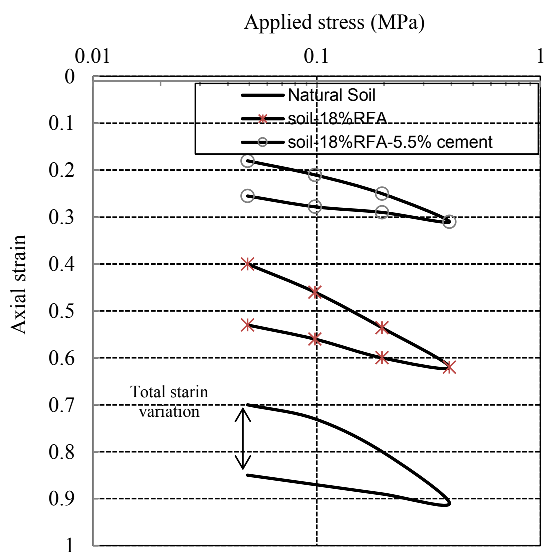


Figure 11: Compressibility of soil-18% RFA -5.5% cement mixture.

6.3 Curing Period Effect on Soil -18% RFA 5.5% Cement and Soil -9% CW Mixtures

Figures 12 and 13 show the relation between the maximum compressive strength and curing periods of soil -18% RFA - 5.5% cement and soil -9% CW mixtures, respectively. A modification in the compressive strength of soil -18% RFA -5.5% cement and soil -9% CW mixtures was observed with the improvement in the curing periods.

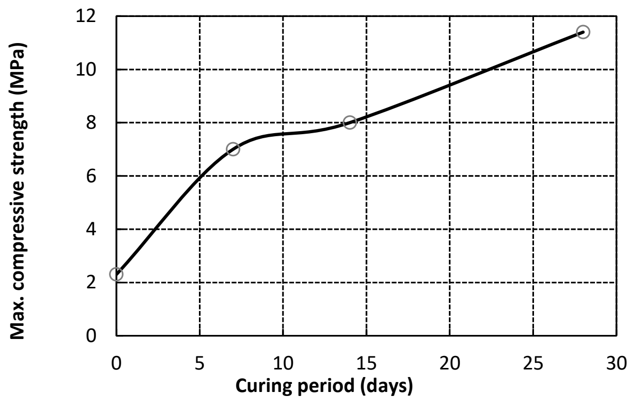
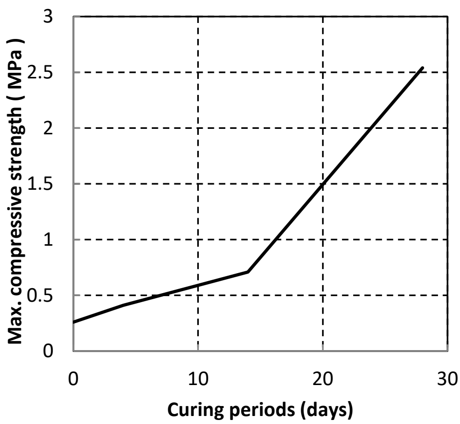
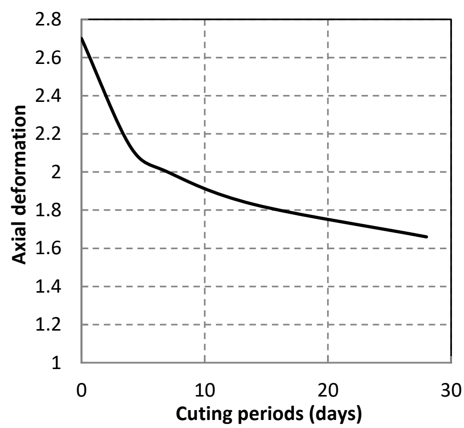


Figure12: Curing period effect on soil-18% RFA -5.5% cement.



(a)



(b)

Figure 13: Curing period effect on (a) Max. Compressive strength, (b) axial deformation of soil -9% CW.

7. CONCLUSIONS

Finally, some findings may be concluded. Adding CW waste materials changes the treated pore soil structure from meso pore size to micro-meso size. It also produced modifications in the treated clayey soil's mechanical properties: an increase in the MDD and maximum compressive strength and a reduction in the rate of axial deformation, accompanied by a decrease in the water retained ability within the treated soil structure. The 18% RFA waste materials could be considered the optimal percentage, at which RFA exhibits increment in the OMC and maximum compressive strength, accompanied by decrement in the MDD and axial treated soil deformation.

Adding RFA to clayey soil shows a distinctive effect on its pore structure compared to the other additions (i.e., CW), which changed the pore soil structure to predominantly micropore size accompanied by less water-retained capability. The optimum cement activator was around 5.5%, since this percentage with the 18% RFA waste materials had produced a treated soil mixture with high compressive strength and less axial strain variation. The modification in the compressive strength of soil -18% RFA -5.5% cement and soil -9% CW mixture, under different curing periods, proved the continuity of pozzolanic reaction of the added cement in soil-18 %RFA, and the cement presence within the concrete agglomerates materials (CW).

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