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Civil Engineering Journal

Vol. 5, No. 10, October, 2019

Improvement of Geotechnical Properties of Cohesive Soil Using Crushed Concrete

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Received 26 April 2019; Accepted 22 July 2019

Abstract

Some natural resources such as gravel are not renewable, therefore, it is necessary to reduce the use of such resources and replace them with other recycled, economic, and environmentally friendly materials. Recycled crushed concrete aggregates demolished from old buildings and blocks of waste concrete can be used to replace the natural aggregates. The present study focused on using recycled crushed concrete in improvement the chemical and geotechnical properties of soft soil having undrained shear strength of 6.78 kPa. The soft soil samples were mixed with 5, 10, and 15% of crushed concrete. The blocks of waste concrete are grinded by mills to get crushed concrete which passing sieve no. 4. Such aggregates are lighter than natural aggregates and provide a good deformation modulus when mixed with soil. In Iraq, there are hundred thousand tons of concrete blocks used as fences and now considered wastes after removing these security fences, so it's important to interest from recycling of such materials to be used in the improvement wide region of soft soils in Iraq. The results of tests showed increasing the undrained shear strength of soft soil by 175-193.5% and reduced the compressibility of soft by 25-31% measured in terms of compression index.

Keywords: Improvement; Crushed Concrete; Soft Soil; Mixing; Geotechnical Properties.

1. Introduction

The design of the foundations of different structures such as buildings, dams, bridges etc. requires knowing the geotechnical properties of the foundation soil, therefor, laboratory tests are performed to investigate the geotechnical properties of soil. Soils should have adequate bearing capacities to support heavy structures and reduce the compressibility under the applied loads. Therefore, it is important to improve the bearing capacity of weak and soft soils using sustainable materials such as wastes. The results of permanent deformation characteristics of recycled asphalt pavement (RAP), recycled crushed aggregate (RCA), and aggregates of dense grading under triaxial cyclic loads showed that RCA has the lowest permanent deformation among the three materials [1, 2]. The layers of crushed concrete recycled from old demolished structures have self-cementing properties which causes a growth in stiffness of soil mixed with such materials [3]. The fine fraction of the recycled aggregates must be removed if the recycled concrete materials are to be used in drainage layers because the fine particles have the potential for gaining strength by cementing the particles of soil which reduces permeability of soil and efficiency of drainage layer [4].

Molenaar and van Niekerk (2002) studied the behavior of unbound base course materials made from masonry rubble and recycled concrete. The results showed that these materials can be used in road bases due to their good quality [5].

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http://dx.doi.org/10.28991/cej-2019-03091397

McKelvey et al. (2002) observed a reduction in the shear strength of the recycled materials used in vibro-ground improvement techniques. For both wet and dry materials, there was a reduction in the internal drained friction angle from 39 to 32 after mixing clay slurry with the recycled concrete [6]. The recycled aggregates provide a good alternative to natural aggregates as they have a significant shear strength and the friction resistance of recycled aggregates is reduced by repeated loading [7]. Poon and Chan (2006) used crushed concrete in subbases and suggested that different sizes of fine and coarse aggregates require to have specified grading limits for embankments, pavements, bridges, and roads [8]. The shear strength of a soft clayey soil had been evaluated before and after the addition of cement as a stabilizing agent to evaluate the behavior of an embankment of road constructed on a soft clay. The results showed that the cement stabilized soil has a good resistance to shear failure compared to an equivalent layer of compacted sand fill and the unconfined compressive strength of the cement stabilized soil is increased with increasing the cement content and increasing the curing time up to 28 days [9].

Melbouci (2009) studied the shear strength and compaction properties of recycled concrete aggregates experimentally and concluded that the mechanical behavior of the material can be improved by the addition of 10% cement, 6% bricks, and 5% sand particles of sizes smaller than 0.125 mm. There was a reduction in the porosity of the recycled concrete aggregates by 45% after a period between 28 days and 5 years [10]. RCA may provide an increase in the strength of bonding between old aggregates and new cement paste after continuous hydration [11]. Agrela et al. (2012) studied replacing granular materials treated with cement by mixed recycled aggregates obtained from a mixture of masonry and concrete rubbles. The recycled materials provided a satisfactory bearing capacity to the structural road layers and the road surface remained undeformed for two years after construction [12].

The improvement of the mechanical properties of base and subbase layers when stabilized with recycled concrete aggregates (RCA) mixed with limestone aggregates (LSA) have been evaluated by the unconfined compressive strength (UCS) which is influenced by cement content, curing time, and dry density [13]. Laura et al. (2015) found that CBR values for the recycled mixed aggregates and recycled concrete aggregates is lower than that for the natural subbase materials when the recycled materials aren't soaked in water. But when the recycled aggregates are soaked in water will show higher CBR values than the natural aggregates [14]. The main improvement of both recycled materials will occur after 28 days of curing. This increment in the CBR values is resulted from the presence of the anhydrate cement in the recycled materials. The load capacity reaches its higher value after 180 days for the recycled concrete aggregates. The present paper focused on evaluation the effects of crushed concrete on the chemical and geotechnical properties of soft soil to be used as subgrade material in the construction of projects. The crushed concrete obtained from the waste of concrete blocks, so the crushed concrete considered environmentally friendly and sustainable material through reducing using natural resources [15, 16]. In Iraq, there hundred thousand tons of waste of concrete blocks and wide regions of soft soil in the middle and south of Iraq. It's suggested to use these concrete blocks after grinding in the improvement of geotechnical properties of soft soil through increasing the strength of such soil and reduce its compressibility. The soft soil is mixed with several percentages of crushed concrete to measure the improvement of geotechnical properties of soft soil

2. Soil Improvement

Soil improvement is implemented when the supporting soil has undesirable geotechnical properties and the space is limited. Also, improving the soil is considered more economical than using deep foundations. Soil improvement is used to:

a) Prevent future construction settlement.

b) Increase the shear strength of the soil.

c) Enhance the bearing capacity of the soil.

d) Increase dams and embankment stability.

e) Reduce the permeability and quantity of seepage from soil.

f) Avoid soil liquefaction in regions susceptible to earthquakes by increasing the stiffness and density of the soil.

g) Prevent the movement of contaminants in soil to control the environmental impacts of contaminants.

Waste concrete can be recycled and reused in a variety of construction activities such as the construction of pavements to preserve the natural resources and minimize the environmental pollution caused by solid wastes [17-20]. The use of construction and demolition wastes such as recycled concrete aggregates (RCA) is a tempting alternative to the highway engineer. The use of recycled concrete aggregates in pavement construction have been growing in different parts of the world especially in Europe to reduce the extraction of the natural recourses and the consequent environmental impacts. Recycled concrete aggregates can be effectively used in base and sub-base layers of low traffic volume pavements. A growth in stiffness is expected in pavement layers of soil mixed with crushed concrete caused by the self-cementing of the remaining anhydrate cement in the mortar to the fine particles of soil (<5 mm) [15-20].

The properties of weak soils contain fine grained particles must be improved to obtain the desired mechanical behavior. Soil stabilization depends on the chemical reactions that take place between the chemical additive like cement, lime, fly ash etc. and the natural minerals of in-situ soil. One of the methods to improve soil properties is chemical stabilization using of stabilizing agents such as lime and cement which can improve the bearing capacity of the soil. The stabilizing agents are mixed with the natural soil to improve soil strength as these stabilizing agents provide the benefits of bonding the particles of soil, removing excess water from the pores of soil, and filling the empty voids in the soil. The improvement rate depends on the mineral composition of the soil, type and the number of exchangeable cations, and the curing time [21-33].

3. Soil Sampling and Used Materials

Chemical, physical, and mechanical soil tests were performed on the soil samples at the laboratory of soil mechanics at the Department of Civil Engineering/University of Baghdad. Tests were performed on soft soil and improved soil samples. Three percentages of recycled crushed concrete (5, 10, and 15) % were mixed with soft soil to improve its geotechnical properties.

3.1. Soil Sampling

The soil used in the present study was obtained from the site of electric power plant in the campus of the University of Baghdad in Al-Jadiriyah district/Baghdad city. The soil samples were obtained from a depth of 1.5 to 2 m below the ground level. Shelby tubes were used to obtain undisturbed soil samples. After the excavation, the Shelby tubes with a sharp bottom edge were pushed vertically into the soil under hydraulic pressure and extracted after removing the surrounding soil by hand drilling. Also, the soil sample of Shelby tubes is used to calculate the field moisture content (16.5%) and density of the soil (1.715 g/cm^3). Disturbed soil samples are obtained by hand drilling from the test pit. Then, the soil samples are labelled with necessary information and transported to the laboratory of soil mechanics at the University of Baghdad for testing.

3.2. Crushed Concrete

The crushed concrete was prepared by crushing the waste of concrete cubes used in testing the compressive strength of concrete mix. The concrete used to produce the cubes was prepared by mixing cement, sand, and gravel with adequate water/cement ratio. The mix is then poured in cubic molds with well compaction to avoid the formation of air voids. The curing process is necessary for the concrete strength gain [3, 8, and 34]. Then, the concrete cubes will be tested to determine the compressive strength of the concrete mix. The concrete cubes will be demolished after reaching the failure strength. The crushed concrete was prepared by crushing the waste of concrete cubes after testing them in the laboratory of concrete testing. The concrete cubes were crushed by mill and sieved through sieve number 4 to provide relatively fine aggregates of size less than 4.75 mm. Three stages were used in the crushing process:

1) In the first stage the concrete cubes were crushed into large pieces by a jaw crusher. This process is required to prepare the concrete to the later stage of crushing.

2) In the second stage the concrete pieces resulted from the jaw crusher were crushed to smaller pieces by a ball mill.

3) In the third stage the small pieces of concrete were transformed into a relatively fine powder by a sand blast. The fine powder resulted from sand blasting is then sieved through sieve number 4 to remove large pieces of gravel or hardened cement mortar and the resulting powder is packed in water proofing bags to protect the crushed concrete from moisture.

3.3. Preparation of Improved Soil Samples

The steps of preparing of soil samples used in tests are listed below [35]:

1) Preparing a clean and dry steel box of dimensions 60×60×40 cm to prepare the soil samples;

2) The soil has a dry density of 1.472 g/cm^3 and the required weight to fill the box is approximately 205.2 kg and divided into four sub-layers each sub-layer has a thickness of 10 cm and a weight of 51.3 kg.

3) Each sub-layer is prepared by mixing the soil in three small plastic containers, each container takes 17.1 kg of dry soil. These small containers are used to facilitate the mixing process of crushed concrete with soft soil. The crushed concrete is added as a percentage of the soil dry weight 5, 10, and 15%;

4) Approximately 3.42 liters of water is added to each plastic container and the soil is thoroughly mixed with water, where the total amount of water is about 20% to get undrained shear strength of 6.78 kPa.

5) After the mixing process, the three small plastic containers are poured in the steel box one after the other with gentle tamping to achieve the field density.

The designation of tested soil samples in the present study is given in Table 1.

Table 1. Designation of tested soil samples

Soil symbol	Definition
S	Soft soil sample
C	Recycled crushed concrete
SC5	Soft soil mixed with 5% of recycled crushed concrete
SC10	Soft soil mixed with 10% of recycled crushed concrete
SC15	Soft soil mixed with 15% of recycled crushed concrete

3.4. Chemical Properties of Soil Samples

The chemical tests performed on soft and improved soil samples at the centre of construction research/Ministry of Science and Technology to measure the impacts of the chemical composition of soft and improved soil samples on the geotechnical properties of the soil. The chemical tests conducted according to ASTM standards are listed in Table 2.

Table 2. The chemical tests

Test	Symbol	ASTM Standard
Three sulfate ions	SO_3	D516
Chloride content	Cl^{-}	D512 A
Calcium oxide content	CaO	D4373
Total dissolved solids	TDS	D5907
pH value	pH	D4972

3.5. Physical Properties of Soil Samples

The physical tests are conducted at the laboratory of soil mechanics/University of Baghdad on soft and improved soil samples according to the ASTM standards (2003). The conducted physical tests are listed in Table 3.

Table 3. The conducted physical tests

Test	Symbol	ASTM Standard
Specific gravity	Gs	D854
Atterberg's Limits	LL, PL, PI	D4318
Particle size distribution	Finer-size curve	D422
Compaction test	Compaction curve	D698

3.6. Mechanical Properties of Soil Samples

The following mechanical tests are performed on soft and improved soil samples according to ASTM standards (2003).1-D consolidation tests conducted on soft and improved soil samples according to ASTM (D2435). The odometer ring used in the tests of 18 mm in height and 50 mm in diameter. . The shear strength of soil is measured in terms of the parameters, cohesion (c) and angle of internal friction (φ). These parameters are measured by unconfined compressive strength test (UCT) according to the ASTM (D2166). The unconfined compressive strength test is conducted on soft and improved soil samples as shown in Figure 1. The soil specimen is a cylinder of height 76 mm and a diameter of 38 mm.

Figure 1. Soil sample tested by UCT

A summary of research methodology can be shown in the following flowchart (Figure 2).

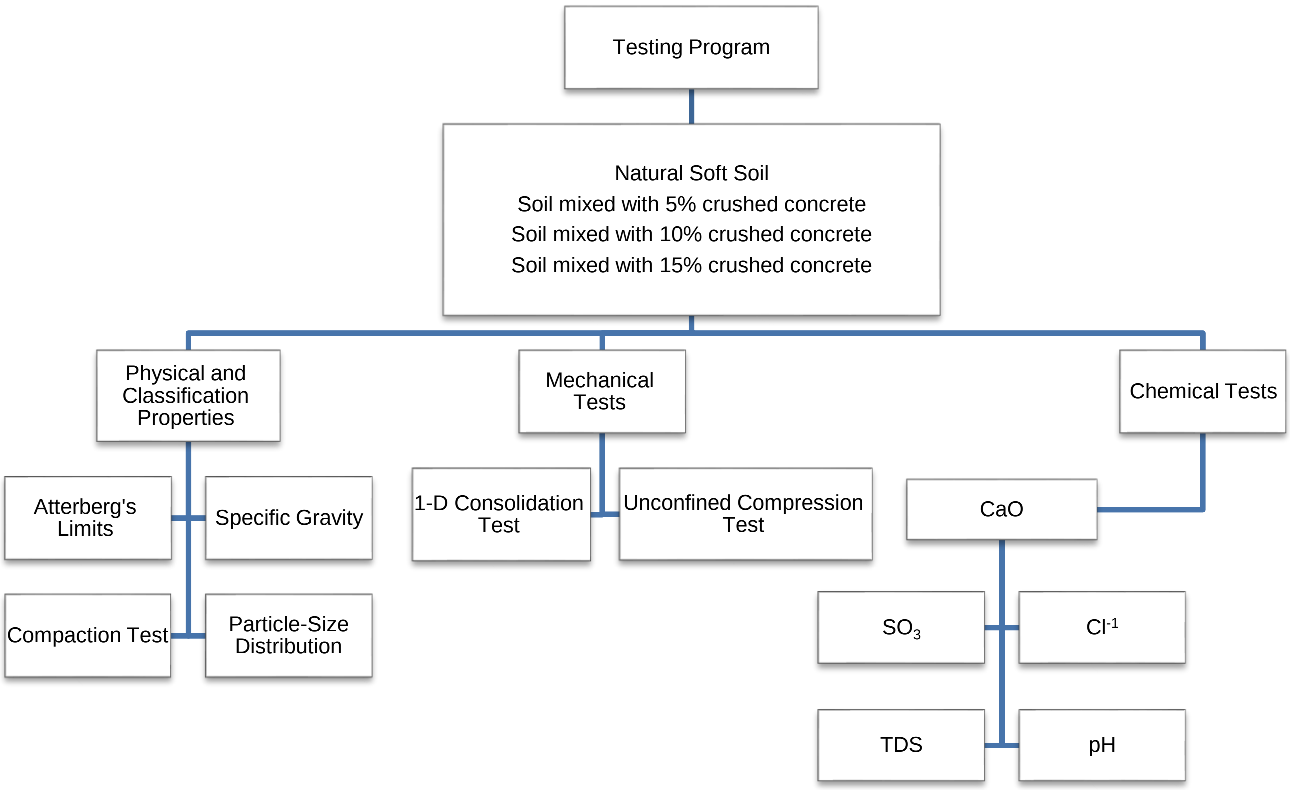

Figure 2. Flowchart of experimental testing program

4. Results and Discussion

The results of conducted tests can be categorized into three main parts: the first one devoted for the chemical properties of improved soil samples and the second part devoted for the impacts of crushed concrete on the physical properties of samples. While, the third part is devoted for the changes in mechanical properties of soil samples.

4.1. Results of Chemical Tests

The results of chemical tests are given in Table 4. The SO_3 content of soil is approximately twice that of crushed concrete, but SO_3 content for the soil-concrete mixtures shows a gradual increase as the crushed concrete content increases in the soil. Cl^- contents of soil, crushed concrete, and the soil-concrete mixtures are approximately constant. CaO content of crushed concrete is larger than that of the soil and the CaO contents of the mixtures increase to a maximum value of 22.19% at a crushed concrete content of 10% and then decreases as the concrete content increases in the soil. TDS content of the concrete is approximately four times the TDS content of the soil and the TDS contents of the soil-concrete mixtures increase to a maximum value at a crushed concrete content of 10% and then decrease as the crushed concrete content increases in the soil. pH values show that the crushed concrete is more alkaline than the soil and the pH value has a maximum value of 10.9 at a crushed concrete content of 10 %. It's clear that mixing the soft soil with 10% of crushed concrete causes increasing the main chemical properties of soft soil, but higher percentages of crushed concrete causes gradual decreasing of these properties but still higher than that of soft soil.

Table 4. Results of the chemical tests

Sample type	SO_3 (%)	Cl^- (%)	CaO (%)	TDS (ppm)	pH value
S	0.33	0.0354	19.06	0.99	9.0
C	0.16	0.0354	30.41	4.45	11.4
SC5	0.29	0.03543	18.41	1.17	10.3
SC10	0.37	0.0355	22.19	2.12	10.9
SC15	0.29	0.03541	17.73	1.80	10.8

4.2. Results of Physical Tests

The physical properties of soil are important in classification of soil and specify the adequacy of using such soils in the construction projects. The specific gravity tests performed on the soil samples showed a significant increase of Gs value from 2.62 to be 2.72 at a crushed concrete content of 5% and the results fluctuate as the concrete content increases as shown in Figure 3. Mostly, the density of crushed concrete is higher than that of soft soil, so mixing crushed concrete with soil will raise the Gs value of mixture.

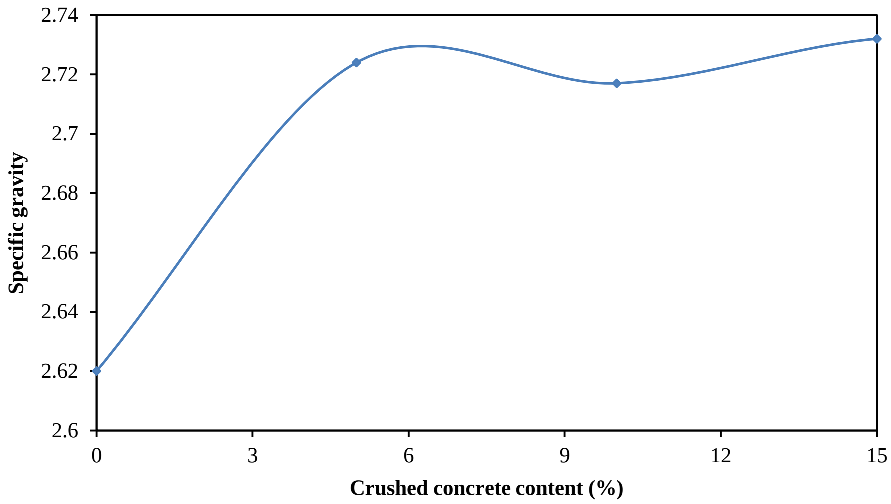

Figure 3. Variation of Gs with crushed concrete content

The results of Atterberg's limits tests showed an increase in the liquid limit (LL) as the content of crushed concrete increased, while there is no significant change in the plastic limit (PL) as shown in Figure 4. According to the Casagrande's plasticity chart, the soil is classified as low plasticity soil. This increase in liquid limit may be caused by the absorption of water by the crushed concrete. The results of Atterberg's limits are agreed with Raghunandan and Lakshmi [36], they found adding admixtures to the soil such as cement, fly ash, rice husk, and stone dust can decrease the plasticity of the soil as the plasticity index is decreased due to increasing the plastic limit.

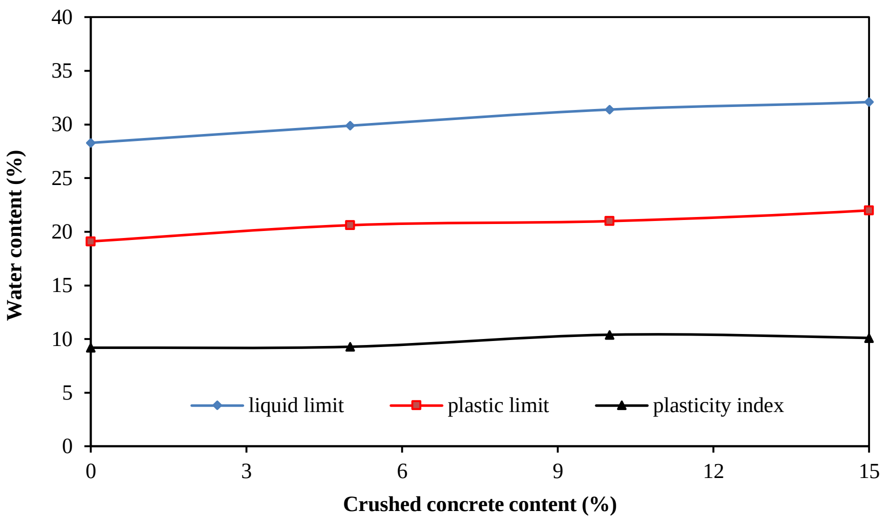

Figure 4. Variation of Atterberg's limits with crushed concrete content

The particle size distribution curves for the soft and improved soil samples are shown in Figure 5. The percentage of the fine material is decreased as the concrete content increased. This might be caused by the concrete being coarser than the soil. The time required for the process of sedimentation of the particles in the hydrometer is decreased by increasing the content of the added crushed concrete due to increasing the size of particles. Also, the chemical reactions between clay minerals and crushed concrete components will act as mass material rather than as segregated particles as in soil alone.

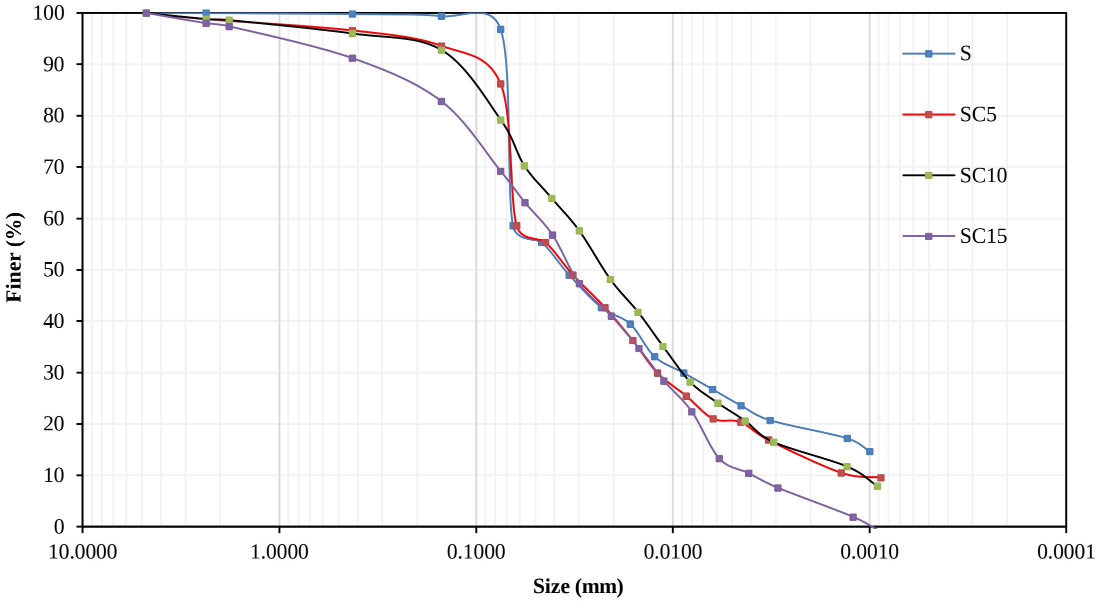

Figure 5. Particle-size distribution curves

Compaction tests are performed on soft and improved soil samples to obtain the maximum dry density and optimum moisture content which are important to calculate the compaction energy and water content that must be added to soil in case of using such soil as subgrade material. The variation of the maximum dry density and optimum water content with content of crushed concrete are shown in Figure 6. The results of compaction curve showed that the maximum dry density is decreased at a crushed concrete content of 5% and then increases until reaching a maximum value of 1.81 g/cm^3 at a crushed concrete content of 15%. The value of optimum water content showed a slight increase at crushed concrete contents of 5 and 10% and then decreases to a minimum value of 15.2% at a crushed concrete content of 15%. It is obvious that the highest maximum dry density and lowest optimum water content are achieved at a crushed concrete content of 15%. Most of literature refer to the addition of cement to a sandy silty clay soil can increase the maximum dry density and the optimum water content. The mixing of soil with crushed concrete will reduce the surface area required to be moisturized which causes reduction in the value of optimum moisture content, but the rehydration of cement of crushed concrete will help to increase the bonding between soil particles and then density of soil.

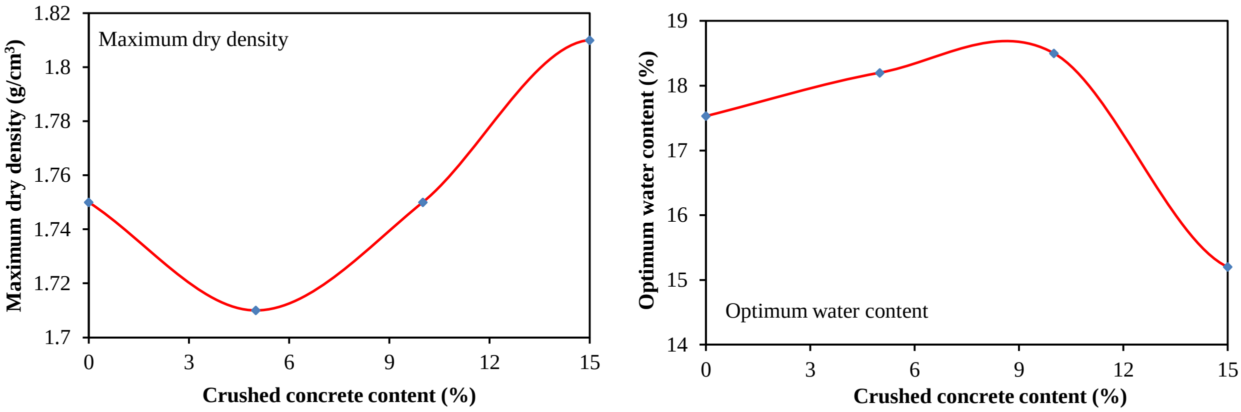

Figure 6. Variation of maximum dry density and optimum water content with crushed concrete content

4.3. Results of Mechanical Tests

The mechanical properties of soil are important in evaluating the shear strength of soil and its compressibility which reflected by bearing capacity of soil. These properties are measured in terms of shear strength and 1-D consolidation tests. The shear strength of soil is measured in terms of UCT. The results of the shear strength tests are presented in Table 5. The variation of axial stress with axial strain obtained from UCT are shown in Figure 7. The value of undrained shear strength (c_u) increased significantly with increasing the content of crushed concrete mixed with the soft soil. The undrained shear strength measured by UCT is increased by 175-193.5% when content of crushed concrete increased from 5 to 15%. The unhydrated cement mortar presented in the crushed concrete increases the bond between the soil particles and thus the soil cohesion is increased. The recycled aggregates used in the production of concrete have the property of self-cementing caused by the remaining anhydrated cement in the fine particles mortar (<5 mm) [37]. The self-cementing property of the recycled crushed concrete increases the strength of the treated soil, but as the plasticity of the soil is decreased by the addition of crushed concrete, the soil becomes more brittle. The unconfined compression tests provide no confinement to the soil sample, the soil sample starts to break to pieces at relatively low stresses.

The results of the 1-D odometer test are presented in Table 5. The initial void ratio values (e_o) fluctuate and the values are nearly constant as the crushed concrete content increases. The final void ratio (e_f) values were increased may be due to the dissolving of the crushed concrete in water as the soil sample is soaked in water for 24 hours before the loading process. The compression index (c_c) shows nearly a gradual reduction with increasing the crushed concrete content because the self-cementing of the crushed concrete increases soil strength and thus reduces the compression of the soil. The compression index decreases by 25-31% with increasing crushed concrete content from 5 to 15%. Also, the swelling index (c_r) shows a gradual reduction with increasing the crushed concrete content in the soil.

Table 5. Results of shear strength and 1-D consolidation tests

Soil sample	c_u (kPa) from UCT	e_o	e_f	c_c	c_r	c_v (cm^2/s)	D (MPa)	k×10^{-7} (cm/s)
S	7.00	0.644	0.400	0.250	0.025	0.0029	2.33	1.240
SC5	19.30	0.697	0.487	0.188	0.025	0.0030	2.72	0.011
SC10	20.35	0.632	0.458	0.171	0.021	0.0024	3.45	0.696
SC15	20.55	0.686	0.497	0.173	0.017	0.0022	3.01	0.724

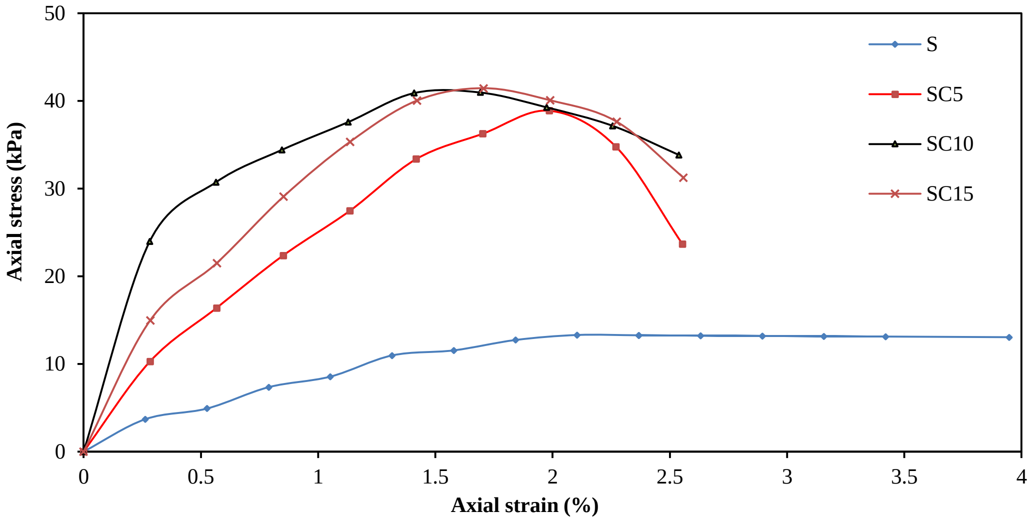

Figure 7. Variation of the axial strain with the axial stress of UCT

5. Conclusion

Natural resources are limited and their extraction requires energy consumption and produces environmentally harmful emissions. Thus, recycled materials such as construction and demolition wastes can reduce the cost of energy consumption and emissions of gases and can be used in many civil engineering works. One of the constructions and demolition wastes is the concrete blocks. In Iraq, there are hundred thousand tons of concrete blocks used as fences for security purposes and after improvement of security situation, these concrete blocks become wastes, so it's important from sustainable and environmental aspects using such wastes in the construction projects. The soft clayey soil samples were mixed with 5-15% of crushed concrete calculated by weight of soil. Crushed concrete aggregates can improve the bearing capacity of soft soils due to rehydration of the remaining unhydrated cement in the cement mortar which can cause self-cementing of soil particles. The mixing of soft soil with crushed concrete increases the soil cohesion and reduces the soil compression and swelling and reduces fines particles in soil. The undrained shear strength of improved soil increased by 175-193.5% and the compressibility of such soil samples decreased by 25-31%.

6. Acknowledgements

The authors expressed their thanks and appreciation to the staff of soil mechanics laboratory at the Department of Civil Engineering/University of Baghdad for their assist in conducting the laboratory tests.

7. Conflicts of Interest

The authors declare no conflict of interest.

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