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USING SUSTAINABLE MATERIAL IN IMPROVEMENT THE GEOTECHNICAL PROPERTIES OF SOFT CLAYEY SOIL

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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 can be used to replace natural aggregates. There are hundreds and thousands of tons of concrete blocks used as fences and now considered as wastes after removing these security fences, so it's important to recycle these materials and use them in the improvement of a wide range of soft soils. The present study focuses on using recycled crushed concrete in the improvement of the chemical and geotechnical properties of soft soils having undrained shear strength of 6.78 kPa, field density of 1.71 g/cm^{3,} and natural water content of 16.5 %. The soft soil samples were mixed with 5, 10, 15, 20, and 30% of crushed concrete. Such aggregates are lighter than natural aggregates and provide a good deformation modulus. The results of tests showed an increase in the undrained shear strength of the soft soil by 40-145% and a reduction in the compressibility of the soft soil, where the compression index decreased by 25-47%. Also, mixing the soft clay with crushed concrete causes increasing the sulfate content and alkalinity of the soil.

Keywords: Crushed concrete, Chemical properties, Geotechnical properties, Sustainability, Soft soil.

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. So, laboratory tests are performed to investigate the geotechnical properties of soil. Soils should have adequate bearing capacities to support heavy structures. Therefore, it is important to improve the bearing capacity of weak and soft soils. The permanent deformation characteristics of recycled asphalt pavement (RAP), recycled crushed aggregate (RCA), and aggregates of dense grading by applying triaxial cyclic loads and the results 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 [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 re-cementing which reduces permeability [4]. The unbound base course materials made from masonry rubble and recycled concrete can be used effectively in road bases due to their good quality [5]. A reduction in the shear strength of the recycled materials used in vibro techniques of ground improvement was observed. 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]. Also, the recycled aggregates provide a good alternative to natural aggregates as they have a significant shear strength and the recycled aggregates friction resistance is reduced under repeated loading [7]. Generally, it is suggested to use crushed concrete in subbases and suggested that different sizes of fine and coarse aggregates require to have specified grading limits to be used in different types of projects such as embankments, pavements, bridges, and roads [8].

The shear strength and compaction properties of recycled concrete aggregates can be improved by addition of 10% cement, 6% bricks, and 5% sand of particle size smaller than 0.125 mm [9]. There was a reduction in the porosity of the recycled concrete aggregates of about 45% at a period between 28 days and 5 years. While this reduction in porosity is smaller in natural aggregates. RCA may provide an increase in the strength of the bond between old aggregates and new cement paste after continuous hydration [10]. Replacing 100% of cement used treatment of granular materials by mixed recycled aggregates obtained from a mixture of masonry and concrete rubbles provided satisfactory bearing capacity to the structural road layers and the road surface remained undeformed for two years after construction [11]. 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 [12]. Laura et al. found that California bearing ratio (CBR) values for the recycled mixed aggregates and recycled concrete aggregates are 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. The main improvement of both recycled materials will occur at 28 days of curing. This increment in the CBR values is caused by the presence of the non-hydrated cement in the recycled materials. The load capacity reaches its higher value after 180 days for the recycled concrete aggregates [13].

The present paper focused on evaluating 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. In Iraq, there hundred thousand tons of waste concrete blocks and a wide region of soft soil in the middle and south of Iraq. It's suggested to use these concrete blocks in the improvement of soft soil by crushing the concrete into small size particles and mixed with several percentages to measure the effects of improvement. The sustainable aspects of using such material is to reduce using natural resources, reduce carbon emission, and clean the environment from wastes.

2. Sustainable Improvement

Sustainable ground improvement is a crucial part of the present development of infrastructures. Modern policy of sustainable environments requires processes to be free of chemicals, free of noise, and have low carbon emissions while being economical [14] Geotechnical engineering plays a part in the improvement of societal system stability in seven categories [15]:

- Managing waste.
- Development and recovery of infrastructures.
- Efficiency and transformation of construction.
- National security.
- Discovery and rehabilitation.
- National hazard reduction.
- Frontier development and exploration.

There are four sustainability key areas of research [16]:

- Energy: using alternative technology to reduce the consumption of energy and using renewable energy.
- Materials: finding ways to reuse and recycle materials.
- Pollution: reducing toxicity and pollution of noise, water, and space.
- Waste: recycling and reducing waste and managing the production of wastes.

The principles of sustainability should be implemented for reducing the consumption of energy, greenhouse gas emissions, carbon footprint, and increasing reusing and recycling of materials. Air quality and carbon emissions are directly connected to earthworks operations. The major emissions to air are generated from demolition dust, construction activities and earthworks. Construction vehicles emissions significantly contribute to local air pollution. Therefore, reducing the need for quarrying natural aggregates by using recycled waste materials such as old pavements will reduce landfill costs, project carbon emissions and transportation costs [17].

Several methods of soil improvement are available. The selection of a method of soil improvement is related to the cost of the project, the time available, and the sustainability of the project should also be accounted for [18-21]. One of the soil improvement methods is the use of lime which allows reusing of very soft fine soils in embankment construction. Lime treatment improves soil properties, increases workability, and aids compaction during the earthworks. Lime produces pozzolanic reactions that may resume for years and as a result, there will be a continued increase in strength and stiffness. Also, lime has a good impact on earthworks cost [17, 20, 22-26]. The best stabilization methods will be the ones with the smallest carbon footprint. It is recommended to use other products that provide alkali activation such as quarry waste fines, ashes, slags, and quarry dust along with cement or lime [26-29]. Ashes and fines contain appreciable amounts of oxides such as silicon dioxide, these oxides increase strength and stiffness because they provide pozzolanic activity [22].

3. Experimental Work

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 soil samples improved by several percentages of crushed concrete. Five percentages of recycled crushed concrete (5, 10, 15, 20, and 30) % were mixed with soft soil to improve the geotechnical properties of the soft soil.

3.1. Soil sampling

The soil used in the present study was obtained from the site of the 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 and the depth of the groundwater table was 1.5 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 Shelby tubes used to calculate the field moisture content (16.5%) and the density of the soil (1.715 g/cm^3). Disturbed soil samples are obtained by hand drilling. Then, the soil samples are labelled and transported to the laboratory of soil mechanics at the University of Baghdad for testing. The soil sample is classified as lean clay (CL) according to the unified soil classification system. The unconfined compressive strength tests are conducted on the natural soil samples mixed with several water contents to draw the variation of the unconfined compressive strength with water content is shown in Fig. 1. Disturbed soil samples are prepared by mixing oven-dried soil samples with water. The percentages of water added to the soil are 8, 10, 15, 20, and 25% of the dry soil weight.

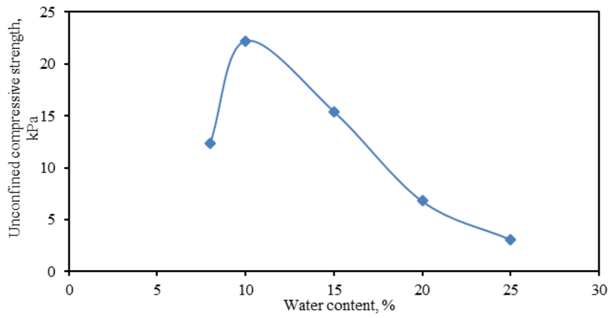

Fig. 1. Unconfined compressive strength of soil for different water contents.

3.2. Crushed concrete

The crushed concrete was prepared by crushing ordinary concrete cubes. 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 moulds. The mix should be well compacted by tamping to avoid the formation of air voids. The curing process, continued for 48 hours, is necessary for the concrete strength gain. 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 testing failure state. The crushed concrete was prepared by crushing the concrete cubes demolished after testing them in the laboratory of concrete testing. The concrete cubes were crushed by the mill and sieved through sieve number 4 to provide relatively fine aggregates. Three stages were used in the crushing process:

- In the first stage, the concrete cubes were crushed into pieces by a jaw crusher.
- In the second stage, the concrete pieces resulted from the jaw crusher were crushed to smaller pieces by a ball mill.
- 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 get rid of any 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 soil samples used in tests are listed below:

- Preparing a clean and dry steel box of dimensions 60×60×40 cm to prepare the soil samples.
- The soil has a dry density of 1.472 g/cm^3 that fills the box has a dry weight of approximately 205.2 kg and is divided into four sub-layers each sub-layer has a thickness of 10 cm and a weight of 51.3 kg.
- Each sub-layer is prepared by mixing the soil in three small plastic containers each container with 17.1 kg dry soil to facilitate the mixing process.
- The recycled concrete is added as a percentage of the soil dry weight (5, 10, 15, 20, and 30) %.
- Approximately 3.42 litres of water are 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.
- 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 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
SC20	Soft soil mixed with 20% of recycled crushed concrete
SC30	Soft soil mixed with 30% of recycled crushed concrete

3.4. Chemical and physical properties of soil samples

The chemical tests performed on soft and improved soil samples at the center of construction research/Ministry of Science and Technology to measure the influence of the chemical composition on the geotechnical properties of the soil. 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 chemical and physical tests are listed in Table 2.

Table 2. The conducted physical 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
Specific gravity	Gs	D854
Atterberg's limits	LL, PL, PI	D4318
Particle size distribution	Finer-size curve	D422
Compaction test	Compaction curve	D698

3.5. 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. The odometer ring used in the tests is 18 mm in height and 50 mm in diameter. The test is performed according to ASTM (D2435). The undrained shear strength of soil (c_u) is measured by unconfined compressive strength test (UCST) and unconsolidated undrained triaxial test (UUT). The unconfined compressive strength test is conducted on soft and improved soil samples as shown in Fig. 2. The soil specimen is a cylinder with a height of 76 mm and a diameter of 38 mm. The test is conducted according to the ASTM (D 2166). While, UUT test is performed on soil samples according to ASTM (D2850-95). The soil specimen is a cylinder of 76 mm height and 38 mm in diameter.

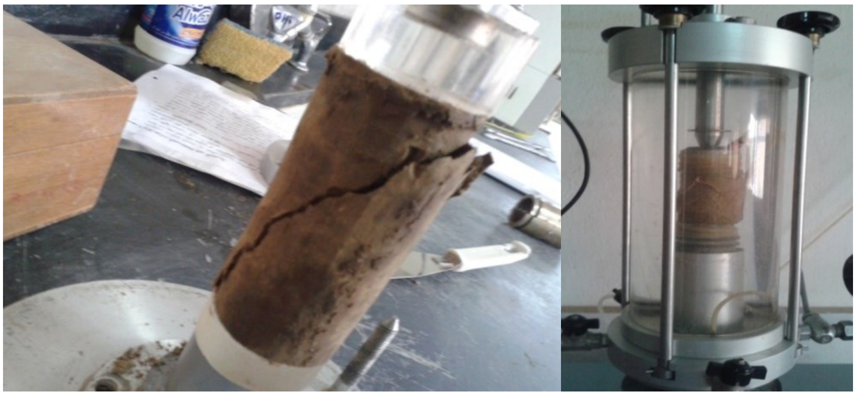

Fig. 2. Soil sample tested by UCST and UUT.

4. Results and Discussion

4.1. Results of chemical tests

The results of the chemical tests are given in Table 3. The SO_3 content for soil is approximately twice of that for 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 for soil, crushed concrete, and the soil-concrete mixtures are approximately constant. CaO content for crushed concrete is larger than that for the soil and the contents for the mixtures increase to a maximum value of 22.19% at a concrete content of 10% and then decreases as the concrete content increases in the soil The small reduction of the (CaO) content of the soil may have resulted from the chemical reactions between the calcium ions with the dissolved silica and alumina. In other words, the high precipitation of $CaCO_3$ makes a significant drop in the calcium oxide content.

TDS content for the concrete is approximately four times the TDS content for the soil and the TDS contents for 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 This increase in the pH value may be attributed to the OH^- ions being dissociated from the calcium hydroxide $Ca(OH)_2$ formed during the hydration of cement.

Table 3. 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	0.0354	18.41	1.17	10.3
SC10	0.37	0.0355	22.19	2.12	10.9
SC15	0.29	0.0354	17.73	1.80	10.8
SC20	0.43	0.0352	18.83	1.83	10.8
SC30	0.44	0.0354	16.78	1.57	10.7

4.2. Results of physical tests

The physical properties of soil are important in the 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 Fig. 3. Mostly, the density of crushed concrete is higher than that of soft soil, so adding crushed concrete will raise the Gs value. The results of Atterberg's limits test showed a slight increase in the liquid limit (LL) as the content of crushed concrete is increased and a significant change in the plastic limit (PL), and then causes a slight decrease in plasticity index. as shown in Fig. 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 are agreed with those obtained by Raghunandan and Lakshmi [30], 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 the increase in the plastic limit.

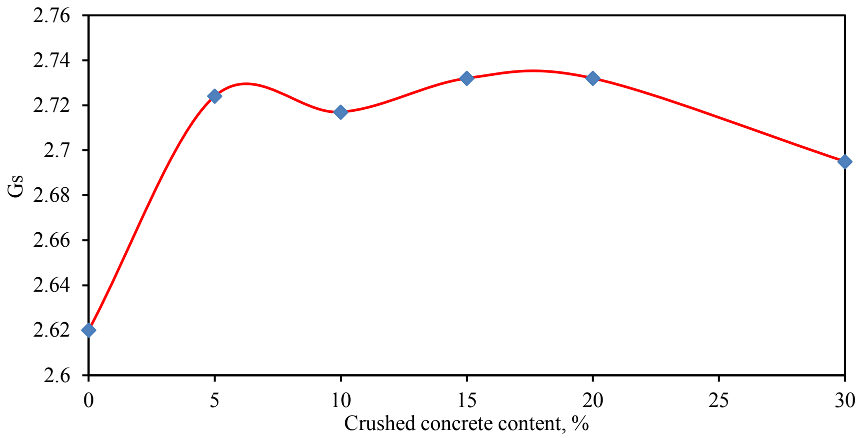

Fig. 3. Variation of Gs with crushed concrete content.

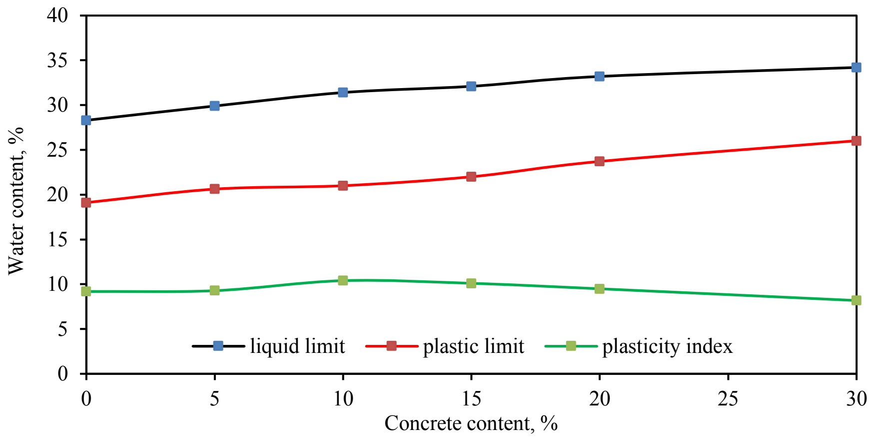

Fig. 4. Variation of Atterberg's limits with crushed concrete content.

The particle size distribution curves for the soft and improved soil samples are shown in Fig. 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.

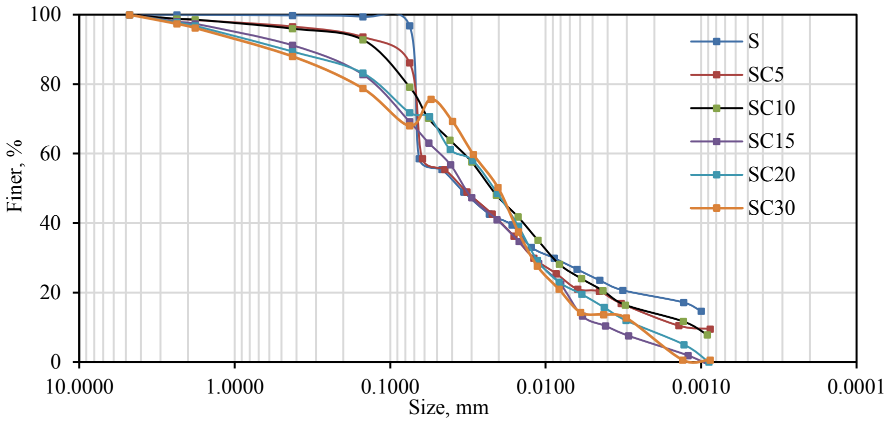

Fig. 5. Grain size distribution curves.

Compaction tests are performed on soft and improved soil samples to obtain the maximum dry density and optimum water content which are important are to calculate the compaction energy and water content to be added to soil in case of using such soils as subgrade materials. The variation of the maximum dry density and optimum water content with the content of crushed concrete is shown in Fig. 6. The results showed that the values of the maximum dry unit weight are decreased at a crushed concrete content of 5% and then increases until reaching a maximum value of 17.76 kN/m^3 at a crushed concrete content of 15% and the value decreases again at a crushed concrete content of 20% and increases again slightly at a crushed concrete content of 30%. The values of the optimum water content showed a slight increase at crushed concrete contents 5% and 10% and then decreases to a minimum value of 15.2% at a crushed concrete content of 15% and then increases slightly at crushed concrete contents of 20% and 30%.

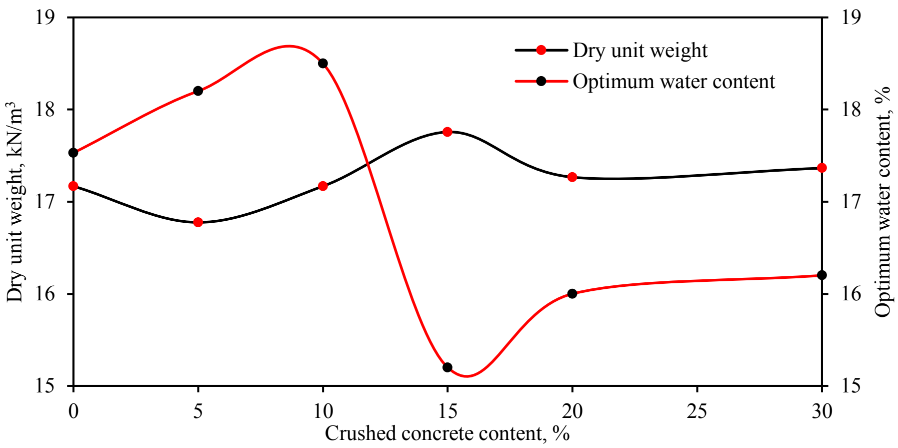

Fig. 6. Compaction curves of tested soil samples.

The highest maximum dry density and lowest optimum water content are achieved at a crushed concrete content of 15%. Most of the literature refers to the addition of cement to a sandy silty clay that 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 a 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 the density of soil.

4.3. Results of mechanical tests

The mechanical properties of soil are important in evaluating the strength and stiffness parameters of soil and its compressibility. These properties are measured in terms of shear strength and 1-D consolidation tests. The shear strength of the soil is measured in terms of UCST and UUT. The results of the shear strength tests are presented in Table 4. The variation of axial stress with axial strain obtained from UCST is shown in Fig. 7 and variation of deviator stress with axial strain obtained from UUT are shown in Fig. 8. The value of undrained shear strength (c_u) significantly increases as the crushed concrete content is increased. The undrained shear strength measured by UCST is increased by 175-388% when the content of crushed concrete increased from 5 to 30%, but the undrained shear strength measured by UUT is increased by 40-145%. The non-hydrated cement mortar presented in the crushed concrete increases the bond between the soil particles and thus the soil cohesion is increased.

Table 4. Results of shear strength tests.

Soil sample	c_u of UCST (kPa)	c_u of UUT (kPa)
S	7.00	48.85
SC5	19.30	68.48
SC10	20.35	80.70
SC15	20.55	88.75
SC20	26.48	100.17
SC30	34.215	119.79

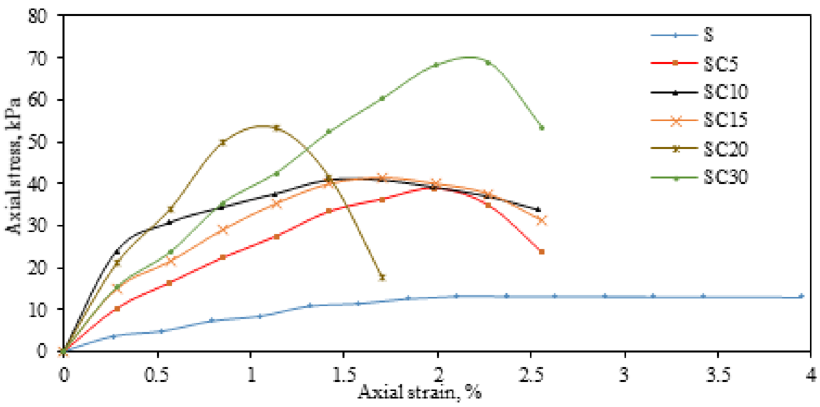

Fig. 7. Variation of the axial strain with the axial stress of UCST.

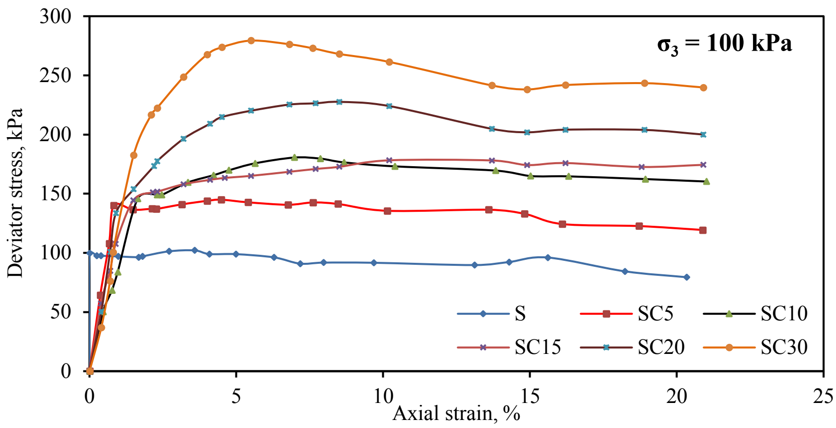

Fig. 8. Variation of the axial strain with the deviator stress of UUT.

The undrained shear strength obtained from UUT is relatively higher than that for the unconfined cohesion may be due to the cell pressure that is applied to the soil specimen which provides confinement to the soil specimen. 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) [31]. 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 and as the unconfined compression tests provide no confinement to the soil sample, the soil sample starts to break into pieces at relatively low stresses. The mode of failure changed from punching shear failure for soft soil to local shear failure with increasing the content of crushed concrete up to 10% but increasing the content of crushed concrete more than 10% will change to general shear failure. 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 25-47% with increasing crushed concrete content from 5 to 30%. Also, the swelling index (c_r) shows a gradual reduction with increasing the crushed concrete content in the soil. The summary of variation c_u measured from UCST and UUT and c_v measured from 1-D consolidation tests are shown in Fig. 9.

Table 5. Results of 1-D consolidation tests.

Soil sample	e_o	e_f	c_c	c_r	c_v cm^2/s	*D* MPa	$k\times10^{-7}$ cm/s
S	0.644	0.400	0.250	0.025	0.0029	2.33	1.240
SC5	0.697	0.487	0.188	0.025	0.0030	2.72	0.011
SC10	0.632	0.458	0.171	0.021	0.0024	3.45	0.696
SC15	0.686	0.497	0.173	0.017	0.0022	3.01	0.724
SC20	0.642	0.502	0.163	0.019	0.0022	8.19	0.262
SC30	0.689	0.589	0.132	0.011	0.0019	15.93	0.124

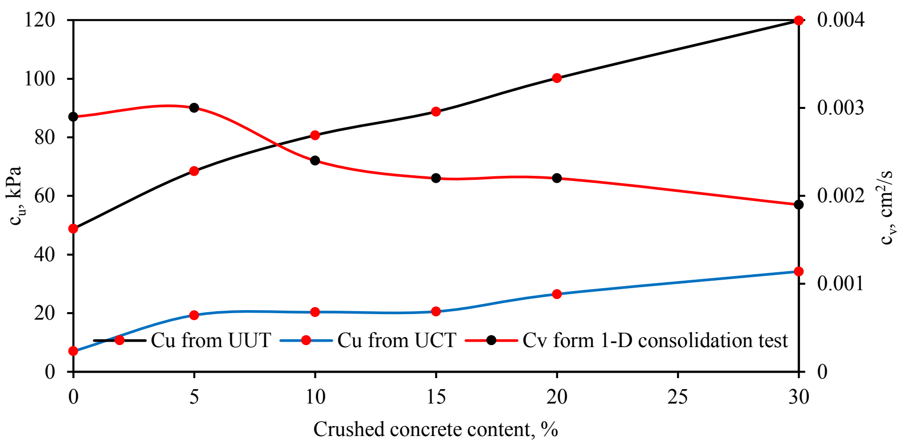

Fig. 9. Variation of c_u and c_v with the crushed concrete content.

5. Conclusions

The main conclusions obtained from the results presented in this study can be summarized by the following points:

- The influence of the crushed concrete on the chemical composition of the soil is the decreased content of the CaO and the slightly increased content of the TDS. The pH value of the soil is slightly increased with the addition of the crushed concrete to the soil.
- The addition of the crushed concrete causes an increase in the specific gravity, liquid limit, plastic limit, but the plasticity index almost remains constant.
- The soft soil becomes coarser after the addition of the crushed concrete.
- The addition of the crushed concrete increases the maximum dry density and decreases the optimum water content until a crushed concrete content of 15%, after this crushed concrete content, there will be a reduction in the maximum dry density and an increase in the optimum water content with increased crushed concrete content, but still higher than that of the natural soft soil.
- The addition of the crushed concrete increased the unconfined cohesion of the soil. The values of the cohesion obtained from the unconfined compressive strength tests are 7, 19.3, 20.35, 20.55, 26.48, and 34.22 kPa and the values of the cohesion obtained from the unconsolidated undrained triaxial tests are 48.85, 68.48, 80.7, 88.75, 100.17, and 119.79 kPa for the soil samples mixed with crushed concrete percentages of 0, 5, 10, 15, 20, and 30% respectively.
- The addition of the crushed concrete decreased the compression index, swelling index, and consolidation coefficient and increased the constrained modulus of elasticity.
- Accordingly, the best percentage of crushed concrete can be used to improve the shear strength of soft soil and reduce its compressibility is 30%.

Acknowledgments

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Nomenclatures

$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CL	Low plasticity clay
Cl^-	Chloride content
c	Cohesion of soil, kPa
c_c	Compression index
c_r	Recompression index
c_v	Coefficient of consolidation
D	Constrained modulus of elasticity of soil, MPa
e_f	Final void ratio
e_o	Initial void ratio values
Gs	Specific gravity
k	Coefficient of permeability, m/s
LL	Liquid limit, %
NP	Non-plastic
PI	Plasticity index, %
PL	Plastic limit, %
pH	Hydrogen-ion activity
SO_3	Trioxide sulfate

Greek Symbols

$\gamma_{d,max}$	Maximum dry unit weight, kN/m^3
ω_{opt}	Optimum moisture content, %

Abbreviations

ASTM	American Society for Testing and Materials
BS	British standards
CBR	California bearing ratio
LSA	Limestone aggregates
RAP	recycled asphalt pavement
RCA	recycled crushed aggregate
TDS	Total dissolved solids, %
UCST	Unconfined compressive strength test
UUT	Unconsolidated undrained triaxial test

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