Effect of Steel Fibers on Mechanical Properties of Cement Stabilized Soil

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ABSTRACT.

Recently, many attempts were made to use steel fiber reinforcement to improve some soil properties. In this research, the effect of steel fibers on the compaction and mechanical properties of cement stabilized soil (silty soil) was studied. Variables such as stabilizer (cement) content, amount and type of steel fibers were studied. Results indicate that the addition of fibers leads to increase in the maximum dry unit weight. On the other hand, a maximum value of unconfined and tensile strength were obtained with the addition of 0.5 % short fiber (FS) and 1.5 % long fiber (FL) respectively.

Key Words: Soil Stabilization, Tensile Strength, Cement, Steel Fibers

1. INTRODUCTION.

Over the last few years, environmental and economic issues have stimulated interest in the development of alternative materials that can fulfill design specifications. The well established techniques of soil stabilization and soil reinforcement are often used to obtain an improved geotechnical materials through either the addition of cementing agents to soil (lime, Portland cement, asphalt, etc.) or the inclusion of oriented or randomly distributed discrete elements such as fibers [1,2,3,4].

Stabilized and reinforced soils are, in general composite materials that resulted from combination and optimization of the properties of individual constituent materials. Reinforcing the subgrade soils with short length fibers have evoked considerable interest among both highway engineers and manufacturers for using these materials as reinforcing material in flexible pavement [5,6]. Fibers inclusions cause significant modification and improvement in the engineering behavior of soils [7,8,9].

A number of research studies on fiber-reinforced soils have recently been carried out through unconfined compression test, CBR tests, direct shear tests and flexural tensile strength tests [2,6,8,10,11,12]. It was found that, using fibers increases the strength and durability of the soils, and the increase in strength was accompanied by an increase in the strain to failure. Fiber reinforcement was also found to increase the crack reduction significantly due to the increased tensile strength of the soil [13,14].

In order to provide information to help understand the overall behavior of fiber-reinforced stabilized fine soil with cement, a series of laboratory tests was carried out to define the response of such materials under static compression and flexural loading.

2. EXPERIMENTAL PROGRAM.

2.1 Materials Used.

- Soil.

The Soil used in this study is a silty soil obtained at (1.5 m) depth from Hawi Al-Kanisa district, within Mosul city. Some of the index properties and chemical tests of soil are listed in **Table (1)**, using the relevant tests according to the ASTM standards.

- Cement.

Ordinary Portland cement from Badush cement factory was used in this study. The chemical composition of cement is shown in **Table (2)**.

- Water.

Tap water was used in the preparation of samples as well as in all the tests.

- Fibers.

Steel fiber is a common material which could be used economically to reinforce soil [1,7]. The fiber is available in different length, diameter, material and shape [15]. Two fiber lengths were used in the present study, 16 and 32 mm, denoted by (FS) and (FL) respectively. Some of the properties of steel fiber are shown in **Table (3)**.

2.2 Specimens Preparation.

Soil samples were prepared and compacted according to the (ASTM D-1557) procedure using modified compaction effort. Cement (C) amounts of (2,4 and 6%) were used to stabilize soil. The required amount of water was added after mixing of cement and soil. The mixture was then placed in plastic bags for mellowing time of (24) hours for untreated soil, and (10) minutes for cement treated soil [16]. The mixtures were then compacted in a specific mold corresponding to the required tests. Short fibers 16mm (FS) percentages of 0.5, 1.5 and 3.0 and long fibers 32mm (FL) of 0.5 and 1.5 were used in preparing reinforced soil mixtures. Soil treated with high value of (3.0 %) of (FL) was avoided because it causes clumping of fibers together and makes the mixing process difficult. A total of (18) different mixes were examined. These mixtures were prepared using (2 to 6 %) cement. **Table (4)** provides a summary of the various mixtures and types of tests conducted in this study.

2.3 Strength Tests.

The unconfined compression test was conducted to obtain the strength of untreated and fiber-reinforced soil samples in accordance with (ASTM D-2166) on cylindrical specimens of 50 x 100 mm size.

Brazilian test (ASTM D-1559) was carried out to determine the indirect tensile strength for untreated and treated reinforced soils. A Marshall mold with 100 mm dia. by 50 mm height was chosen to produce the samples under 25 blows of a standard Marshall hammer per face to obtain the modified compaction effort.

The flexural test was conducted on untreated and treated reinforced soil, using prismatic beam (50 × 50 × 300 mm). The specimens were prepared by compacting the soil in four layers using special square base hammer weighing (1652 gm) and falling from (285 mm) to obtain the modified Compactive energy. The specimen was mounted in compression machine and a load was applied at a rate of (0.127 mm/min). The deflection at the center of the beam (bottom) with applied load were recorded every (1 min.) and the flexural strength properties were evaluated.

All prepared samples treated with cement and fibers, were used in the unconfined compression, indirect tensile and flexural tensile tests, and sealed with aluminum foil, plastic bags and finally by paraffin to cure for different curing times (7, 14 and 28) days at a temperature of 25 ^{o}C.

3. RESULTS AND DISCUSSION.

3.1 Compaction Characteristics.

The compaction characteristics of untreated and treated soil with different percentages of cement and fibers are shown in **Fig.(1)**. It can be noted that, the maximum dry unit weight (γ_{max}) decreases and the optimum moisture content (OMC) increases with the addition of cement. In the case of cement, some of compaction effort could be dissipated to break the early cementing bonds created during the mellowing time (10 min.). Similar behavior was obtained by (Al-Jobouri,2007 [16]). The increase of OMC with increasing cement may be due to the more fine materials added, and/or to the hydration of chemical stabilizer. In case of fiber addition, there was no fundamental difference in the OMC of stabilized reinforced soil, while there was a slight increase in the maximum dry unit weight (γ_{max}) This can be attributed to the high density of fibers. Similar behavior was noticed by (Santoni et al. [5] ; Maher and Ho [17]).

3.2 Strength of Natural and Stabilized Reinforced Soils.

Fig. (2) shows the results of the unconfined compressive strength UCS (q_u), indirect tensile strength ITS (σ_{it}) and flexural tensile strength FTS (σ_{ft}) of natural (untreated) and cement stabilized soil. The maximum values of (q_u), (σ_{it}) and (σ_{ft}) of natural (untreated) soil were (500, 30 and 70 kN/m^2) respectively. It is observed that the compressive and tensile strengths increased upon the addition of cement. This belongs to the reaction that may occur between the soil constituents and the cement. The strength increases as the cement content increases.

3.2.1 Cement Content and Curing Period.

Figs. (3,4 and 5) show the effect of cement content and curing period on the (q_u), (σ_{it}) and (σ_{ft}) of silty soil. The data in these figures indicated that the (q_u), (σ_{it}) and (σ_{ft}) increased from (500, 30 and 70 kN/m^2) for untreated soil to (1300, 100 and 345 kN/m^2) : (1900, 180 and 660 kN/m^2) (2825, 210 and 753 kN/m^2) respectively, for 2, 4 and 6 % cement, consequently, an improvement ratio of (2.6, 3.3 and 4.9) : (3.8, 6.0 and 8.57) : (5.65, 7.0 and 10.75) times that of the untreated soil for the same curing period (7 days at 25^{o} C) were obtained. The increase in strength is directly proportional to the increase in cement content with the studied range. It is also found that, generally, maximum values of (q_u) were obtain at (0.5% FS and 0.5% FL) and for all the curing periods. Comparing mix 1 with mix 13 for (7) days curing, it was founde that the compressive strength, indirect and flexural tensile strength increased by almost (2.1, 2.1 and 2.18) times respectively, when cement content was increased from (2.0 to 6.0 %). Higher cement content may lead to much higher strength values but also economical factor should be considered.

From the previous figures It is Also clear that, there was a continuous strength progress with respect to time due cement hydration and pozzolanic reaction between soil particles and chemical stabilizer as well as any complicated reactions causing cementation of soil particles.

3.2.2 Length and amount of fibers.

The effect of length and amount of fiber reinforcement on the strength of stabilized soil were determined as a function of unconfined compressive and tensile strength (indirect and flexural). The inclusion of fiber reinforcement, was mostly found to enhance the strength of stabilized soil as shown in previous **Figs.(3,4&5)**. Unconfined compressive and tensile strengths were determined for natural soil samples and considered to be a reference sample for comparison with different stabilized fibrous soil. As shown in these figures, the strength of stabilized fibrous soil was generally found to decrease, with fiber content. The values of the (qu), (σ_{it}) and (σ_{ft}) decreased from (1500, 135 and 430 kN/m^2 (mix 2) to 1250, 115 and 390 kN/m^2 (mix 4)) : (2150, 220 and 780 kN/m^2 (mix 8) to 1690, 200 and 740 kN/m^2 (mix 10)) : (3200, 245 and 880 kN/m^2 (mix 14) to 2200, 220 and 850 kN/m^2 (mix 16)) for (2, 4 and 6%) cement respectively, when the small fiber (L = 16 mm) increased from (0.5 to 3.0 %). The percent 1.5 % FS (L = 16 mm) gave max. values of indirect and flexural tensile strength, than other percentages of fibers for all percents of cement and curing periods. These values are (170, 270 and 800 kN/m^2) : (575, 950 and 1040 kN/m^2) for (2, 4 and 6 %) cement respectively at (7) day curing, while the percent 0.5 % FS gave max. values of unconfined compressive strength (1500, 2150 and 3200 kN/m^2) for the same cement content and curing periods. **Table (5)** describes in more details the effect of length and amount fibers on the strength of stabilized soil. Generally, the behavior shown in the previous table is constant for different percentages of cement and curing time.

4. CORRELATION OF TEST RESULTS.

To correlate the indirect (σ_{it}) and flexural (σ_{ft}) tensile strengths, with the unconfined compressive strength, (qu), for all percents of cement and fibers and for all curing periods, different models were initially studied to obtain the best fit among these parameters, i.e. (qu), (σ_{it}) and (σ_{ft}). The investigated models were exponential.

The best fitting model for the laboratory data is represented by Excel program and given by the following relationships:

$$\sigma_{it} = 0.0504\ qu^{1.0868} \qquad (R^2 = 0.8816) \qquad (1)$$

$$\sigma_{ft} = 0.2528\ qu^{1.0442} \qquad (R^2 = 0.8731) \qquad (2)$$

The use of correlation formulas suggested above is limited to range of results of the present study. For more general formula, further samples need to be tested.

5. EFFECT OF CEMENT CONTENT.

To statistically and numerically quantify the degree of improvement attained by cement, the (qu), (σ_{it}) and (σ_{ft}) data were analyzed in terms of the stabilizer content. These relationships can be expressed in the following models:

$$qu\ (kN/m^2) = 841.11 + 410.42\ (c) \qquad (R^2 = 0.7167) \qquad (3)$$

$$\sigma_{it}\ (kN/m^2) = 67.778 + 39.583\ (c) \qquad (R^2 = 0.702) \qquad (4)$$

σ_{ft} (kN/m^2) = 304.89 + 132.75 (c) (R^2 = 0.721) (5)

where c = cement percent (%)

The three models (Eqs. 3 to 5) show linear relationships. These relationships indicate that as the stabilizer content increases, the strength will increase almost linearly, All correlations are practically good, as evidenced by the (R^2) values. These models allow the determination of the appropriate control of this stabilizer for any quantum of strength, i.e. (qu), (σ_{it}) and (σ_{ft}).

6. CONCLUSIONS.

Based on the results of this study, it can be concluded that:

1- Cement addition to the silty soil causes a decrease in the maximum dry unit weight (γ_{max}) and an increase in the optimum moisture content (OMC). Adding fibers, lead to a slight increase in the maximum dry unit weight (γ_{max}) of the mixture with no fundamental difference in the OMC of stabilized reinforced soils.

2- Cement stabilization increases the strength of stabilized soils, this increment was found to be directly proportional to the increase in cement content with the studied range. It is also found that, generally, maximum value of compressive strength are obtained at (0.5% FS and 0.5% FL) and for all the curing periods. Higher cement content may lead to much higher strength values of the mixtures. Also, a continuous strength progress of cement stabilized soils was found with respect to time due cement hydration.

3- Fiber reinforcement addition was found to improve the compressive and tensile (flexural and Brazilian) strength .

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Table (1): Chemical & physical properties of natural soil.

Properties	**Hawi Al-Kanisa**
Liquid Limit (%)	24
Plastic Limit (%)	NP
Plasticity Index (%)	-----
Linear shrinkage (%)	0.58
Total Soluble salts (%)	3.5
Organic content (%)	2.1
Specific Gravity	2.65
Gravel (%)	2
Sand (%)	42
Silt (%)	48
Clay (%)	8
Soil Classification	ML

Table (2): Chemical composition of cement.

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	AL_2O_3	Fe_2O_3	SiO_2	MgO	H_2O	L.O.S
Cement	-----	62.2	-----	2.69	5.47	21.8	2.65	0.05	5.14

- **L.O.S** = Loss of Ignition.

Table (3): Properties of steel fiber.

Symbol of steel fiber	**Properties**			
	Length (mm)	**Diameter (mm)**	**Aspect Ratio (L/D)**	**Shape**
FS	16	2.5	6.4	Hooked
FL	32	2.5	12.8	Hooked

Table (4): Mix design and type of tests conducted in experimental program.

Mix NO.	**Mix Design**	**UCS**	**ITS**	**FTS**
1	2 % C	Yes	Yes	Yes
2	2 % C + 0.5 FS (L = 16 mm)	Yes	Yes	Yes
3	2 % C + 1.5 FS (L = 16 mm)	Yes	Yes	Yes
4	2 % C + 3.0 FS (L = 16 mm)	Yes	Yes	Yes
5	2 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes
6	2 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes
7	4 % C	Yes	Yes	Yes
8	4 % C + 0.5 FS (L = 16 mm)	Yes	Yes	Yes
9	4 % C + 1.5 FS (L = 16 mm)	Yes	Yes	Yes
10	4 % C + 3.0 FS (L = 16 mm)	Yes	Yes	Yes
11	4 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes
12	4 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes
13	6 % C	Yes	Yes	Yes
14	6 % C + 0.5 FS (L = 16 mm)	Yes	Yes	Yes
15	6 % C + 1.5 FS (L = 16 mm)	Yes	Yes	Yes
16	6 % C + 3.0 FS (L = 16 mm)	Yes	Yes	Yes
17	6 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes
18	6 % C + 0.5 FL (L = 32 mm)	Yes	Yes	Yes

- **UCS** = Unconfined Compressive Strength, **ITS** = Indirect Tensile Strength. **FTS** = Flexural Tensile Strength, C = Cement.
- All the calculated percentages were based on the dry weight of soil.

Table (5): Serializing of fibers which gives maximum values of strength.

Type of Soil	Type of Strength		
	Unconfined Compressive	Indirect Tensile	Flexural Tensile
Silty Soil	0.5 % FS	1.5 % FS	1.5 % FS
	1.5 % FS	0.5 % FL	0.5 % FL
	0.5 % FL	0.5 % FS	0.5 % FS
	3.0 % FS	3.0 % FS	3.0 % FS
	1.5 % FL	1.5 % FL	1.5 % FL

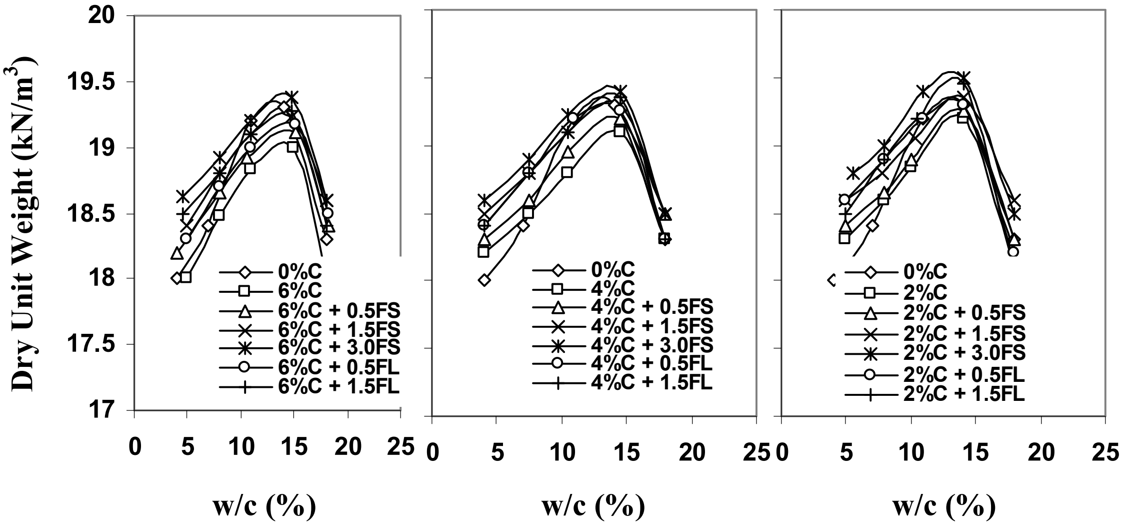

Figure. (1) Compaction Curves of Natural and Stabilized Reinforced Soil

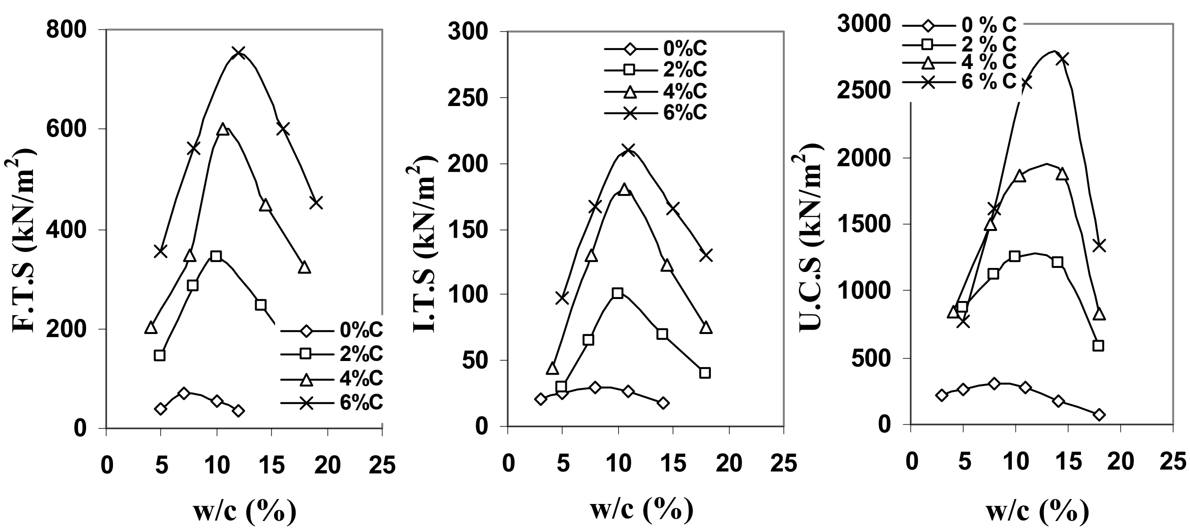

Figure (2): Unconfined Compressive and Tensile Strengths of Stabilized Soil.

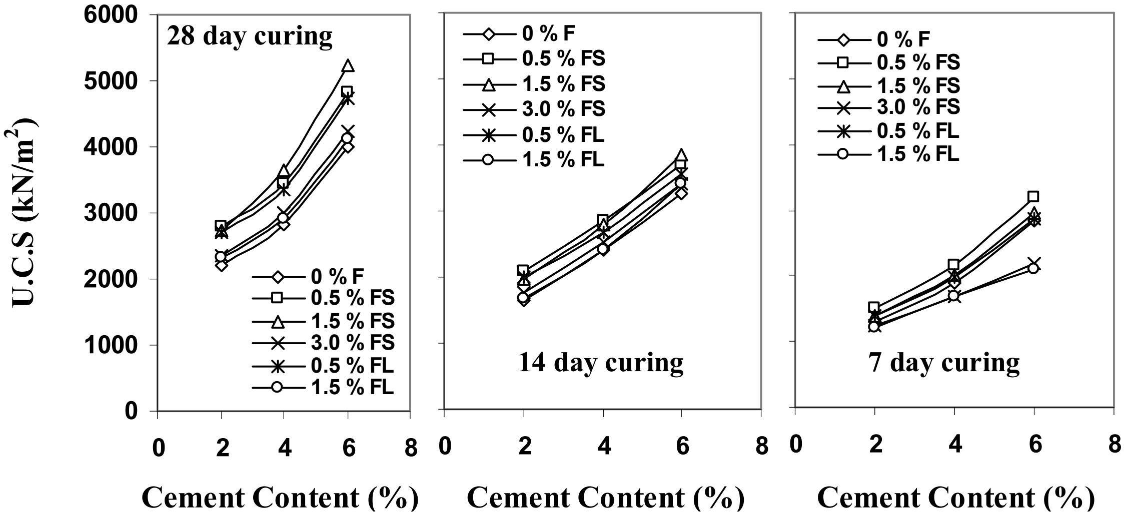

Figure (3): Correlation Between Cement Content and Unconfined Compressive Strength of Stabilized Reinforced Soil.

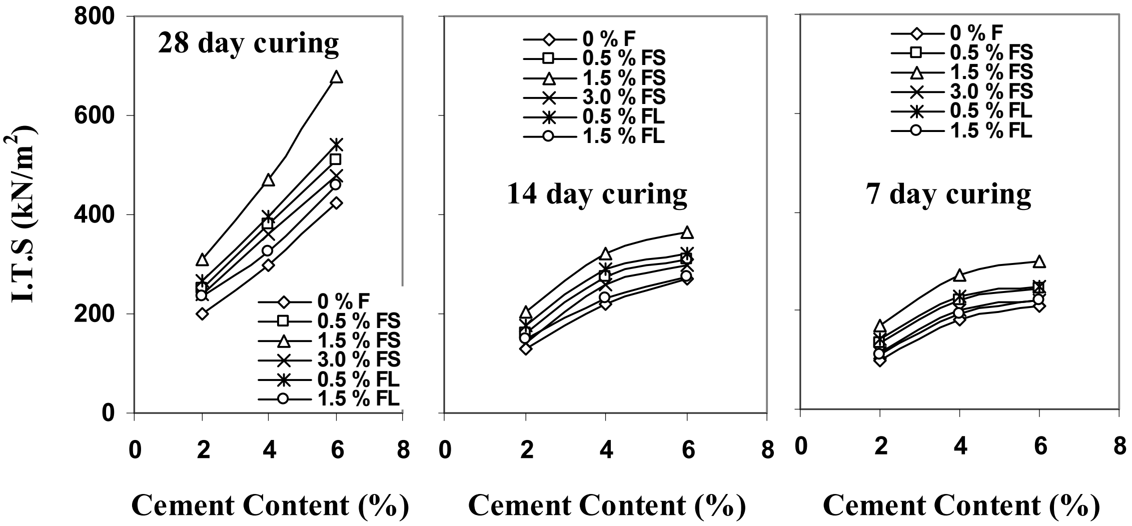

Figure (4): Correlation Between Cement Content and Indirect Tensile Strength of Stabilized Reinforced Soil.

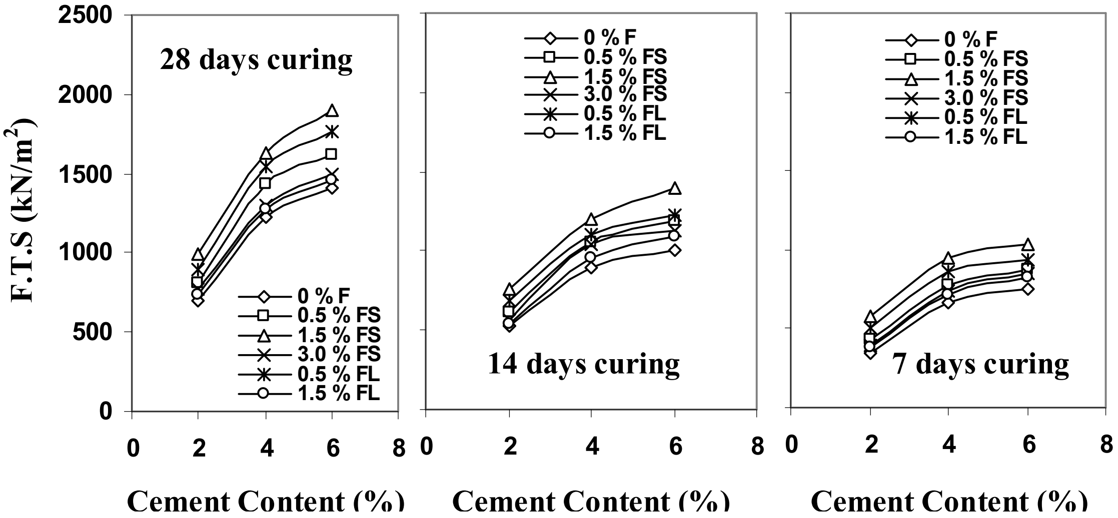

Figure (5): Correlation Between Cement Content and Flexural Tensile Strength of Stabilized Reinforced Soil.

تأثير الألياف المعدنية على الخصائص الميكانيكية للتربة المثبتة بالسمنت

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الخلاصة.

ظهرت في الآونة الأخيرة العديد من المحاولات في استخدام تقنية التسليح بالألياف وذلك لتحسين بعض الخصائص الهندسية للتربة. يهدف هذا البحث إلى دراسة تأثير الألياف المعدنية على خصائص الرص وبعض الخصائص الميكانيكية (مقاومة الانضغاط غير المحصور ومقاومة الشد) لتربة غرينية مثبتة بالسمنت. أظهرت النتائج حصول زيادة في الكثافة الجافة العظمى وكل من مقاومة الانضغاط غير المحصور ومقاومة الشد مع زيادة نسبة الألياف المضافة. كانت أعلى مقاومة انضغاط غير محصور وأعلى مقاومة شد تحدث عند نسبة الألياف (FS % 0.5 و FL % 1.5) على التوالي.

الكلمات الرئيسية: تثبيت التربة، مقاومة الانضغاط، مقاومة الشد، الاسمنت، الألياف المعدنية.