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Experimental evaluation of compressive strength of steel fiber reinforced soil

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Abstract. Today, development of industries has caused production of different scraps. Scraps are recyclable materials left in the environment. Unlike garbage, scraps, particularly those of copper and steel, are of great financial value. The application of steel scraps mixed with soil is one of the solutions to prevent environmental risks of steel. Considering the properties of steel, its scraps made into fibers could be used to reinforce soils and improve their mechanical properties. This study scrutinizes the effects of two types of steel fibers (plain hooked-end and crimped) added to clay with different weight percentages and aspect ratios (L/D) under uniaxial compressive strength test. The results indicated that the compressive strength of steel fiber reinforced soil is to a large extent increased. However, contrary negative effects in the compressive strength are possible once the weight percentage of steel fibers in soil exceeds a certain limit.

Key words: experimental evaluation, reinforced soil, axial compressive strength, steel-fibre, clay.

1. Introduction

According to the US Environmental Protection Agency [1], recycling can have remarkable impacts on the health of the environment. The use of recycled steel instead of crude steel can bring about desirable results such as 70% savings in energy, 90% savings in raw materials and less air pollution. The use of fibers produced from steel scraps prevents the extension of fractures and helps soils to link up to each ether. The type of fibers determines mechanical properties of soils. Nowadays, various types of steel, polypropylene, aramid (Kevlar), carbon and

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glass fibers are used. Steel fibers are of various shapes and are usually divided into four types based on the production methods: 'Straining and shearing steel wires (wire fibers); Rolling and cutting steel plates (cutout or strip fibers); Melting steel and casting fibers (cast fibers); Machining steel plate surfaces (machined fibers) [2].

The fibers used in this study are wire type fibers. There are different tests to examine reinforcement impact [3]. These tests include tri-axial test, direct cutting and uniaxial test. (Radoslaw L. Michalowski, F. ASCE, and Jan cermak 2003) used three types of fibers 25.4 mm long. Monofilament polyamide, Galvanized steel wire and Polypropylene fibers are the types of fibers have been used. However, some of them were of different aspect ratios. The results of the drained tri-axial tests on the fiber-reinforced sand samples are reported. Investigations showed that adding a small amount of synthetic fiber like polyamide and polypropylene increases fracture stress in composites.

However, these fibers increase compressive strength at rupture point. On the other hand, steel fibers (with the aspect ratios L/D=85) in this research were examined in two types of soils, well-graded sand and poorly graded sand. The findings of the research indicated that with a 0.5% fiber addition to the soil, well-graded sand acquired more shear strength than poorly graded sand. Yet, an increase of fiber contents to 1.5% yielded contrary results [4]. (Esmaeel Masoomi 2014) studied soil reinforcement with polypropylene. To investigate and measure the impact of various variables such as fiber type, weight percentage and ratio of fiber dry weight to the reinforcement dry weight (distributed randomly), synthetic fibers such as polypropylene were used for the first time with polymeric resins like urea formaldehyde, polyvinyl alcohol and polyvinyl acetate in CBR test. He tested the behavior of soil combined with resin and propylene fibers 6 mm, 12 mm and 19 mm long and 0, 0.5, 1.5 and 2.5 weight percentages. The results revealed that the best arrangement in combining soil with 12mm polypropylene fibers of 1% weight percentage is the combination with urea formaldehyde. This combination increases the bearing capacity of soil in CBR test, in dry and saturated states, more than 9.7% and 13.9% respectively [5].

The mechanical properties of fiber–soil composites have been studied by several authors through laboratory tests, such as a triaxial compression test [6-7], unconfined compression test [8-9], direct shear test [10-13] plate load test [14], compression test [15], and California Bearing Ratio test. Many other researchers have worked on fiber reinforced soils [16-22]. All these studies demonstrated that the reinforcement of soil with discrete fibers is an effective technique and can significantly improve the mechanical properties of soils. However, as opposed to the aforementioned mechanical tests, the tensile test on fiber reinforced soil has not received the attention it deserves, even though the tensile strength is recognized as the main mechanical factor controlling soil cracking.

(Cristello et al. 2015) investigated the effect of soil reinforcement with separated fibers on the clayey sand soils, in which they implemented the seismic wave propagation test. Main purpose of this study is to evaluate the effects of GFRP on

bearing capacity and shear strength of clayey soil [23]. In final, (Sahebkaram and Dabiri 2017) observed the effects of the several fibers type application on soft soil compared; tests results showed that polypropylene increased the bearing capacity more than other fibers. In continue, materials used and methodology described [24].
Although the effect of steel fibres in concrete has been studied (Jadidi, A. et al. 2017) by a number of researchers [25], the effect of such fibres on the behaviour of chemically stabilised soils has also largely been ignored, probably due to corrosion problems. The few studies in this area have, however, revealed that the inclusion of short steel fibres in a soft soil (Güllü and Khudir, 2014) stabilised with high binder contents (higher than 10%) induces a reduction in flexural strength, while the use of short steel fibres in a low-plasticity silt stabilised with 4% of lime causes an increase in compressive strength [26]. The aim of this work was to contribute a better knowledge of the compressive behaviour of stabilised soft soil with steel fibres. For that purpose, uniaxial compressive test was applied on the samples 24 hours after being made. To provide repeatability, three samples were made for every option in the test, the average results is subsequently presented as parametrical amounts.

2. Experimental procedure

The test materials, preparation of specimens and test methods are described in the following sections.

2.1. Materials

2.1.1 Soil

The soil used in all tests is clay from Sivak, Markazi province. The results of clay compaction tests showed a maximum dry specific gravity of 15.8 kg/cm^3, a minimum dry specific gravity of 14.2 kg/cm^{3}and a specific density of 2.65. Different tests performed on the soil used revealed high plasticity index.

2.1.2. Reinforcing Elements

The reinforcing elements are two types of steel fibers: plain hooked-end and crimped (fig.1) with aspect ratios of 40, 45 and 50, specific gravity of 7850 kg/cm^3, tensile strength of 650 MPa and elasticity module of 212 GPa.

Fig. 1. Steel fibers.

2.1.3. Preparation of samples

First, soil is mixed with water with an optimum moisture content of 11.9%. Fibers are distributed on the surface and properly mixed with soil using a trowel. The mixture is then poured into the mold. To avoid test errors, top of the sample is leveled after compaction using a ruler. The degree of compaction is the same for all samples. After 24 hours, the sample is brought under uniaxial compressive test device to measure the compressive strength of the sample in kg/cm^2.

2.1.4. Uniaxial compressive strength test

Considering the fact that most of the properties of soil like tensile strength, permeability and wear resistance are directly related to its compressive strength, precise calculation of this strength is of central significance. Generally, cylindrical or cubic samples are used in determining compressive strength. The tests in this research are carried out as per [27] on 200 mm ×100 mm cylindrical samples (fig.2).

a) pre-test sample b) post-test sample

Fig. 2. Cylindrical test samples made of soil and fibers.

3. Results and discussion

To investigate compressive strength, uniaxial compressive test was applied on the samples 24 hours after being made. To provide repeatability, three samples were made for every option in the test, the average results is subsequently presented as parametrical amounts. Table 1 shows the number of tests, fibers' aspect ratios and various weight percentages.

Table 1. Tests characteristics

Percentage	**Fiber Percentage**	**Aspect ratio (L/D)**	**Number of samples made for each option**
Control sample (soil with no fibers)	-	-	
Plain hooked-end fibers	1	40	
		45	
		50	
	3	40	3
		45	
		50	
	5	40	
		45	
		50	
	7	40	3
		45	
		50	
Crimped fibers	1	40	
		45	
		50	
	3	40	
		45	
		50	
	5	40	
		45	3
		50	
	7	40	
		45	
		50	
Σ			75

3.1. Compressive Strength of Soil and Steel Fiber Mixture

The results related to the compressive strength of the mixture of soil and fibers with three types of aspect ratios (L/D) are presented.

3.1.1. Fibers with the Aspect Ratio of 50 (L/D)

Table 2 shows the impact of two types of fibers, plain hooked-end and crimped with the aspect ratio of 50 (L/D) =50, (Fiber length=L and Fiber diameter=D) with weight percentages of 1,3,5,7 on compressive strength. When soil is reinforced, its compressive strength increases. This increase can be up to 75% and 93% for plain hooked-end and crimped steel fiber reinforced soils respectively.

Table 2. Compressive Strength changes of soil reinforced with fibers with the aspect ratio of 50

Compressive strength relative changes for fiber reinforced soil compared to soil with no fibers	**Average compressive strength, Kg/cm²**	**Compressive strength of three samples, Kg/cm²**			**Crimped fibers, (%)**	**Plain hooked-end fibers, (%)**
0	3.56	3.7	3.55	3.45	-	-
16	4.15	4.15	4.08	4.2	-	1
49	5.31	5.55	5.25	5.2	-	3
75	6.4	6.3	6.6	6.3	-	5
71	6.1	6.4	5.8	6	-	7
40	5.16	5.18	5.1	5.2	1	-
76	6.3	6.25	6.45	6.1	3	-
93	6.88	6.81	6.95	6.9	5	-
88	6.7	6.65	6.8	6.6	7	-

In order to evaluate the impact of steel fibers on the compressive strength (fig.3) of reinforced soil, changes in the compressive strength of reinforced samples with different fiber percentages are shown in fig. 4. The results in fig. 4 show that steel fibers increase soil compressive strength. The increase continues as far as fiber content does not exceed 5%. A content of 7% fiber is of contrary impact to soil compressive strength. As shown in fig. 4, crimped fibers have more positive impacts than plain hooked-end fibers. It should be noted that as steel fibers are added to the soil sample, after a long time (long term), the compressive strength changes (as its shown above). The compressive strength of the fiber reinforced soil increases and Since the percentage of steel fibers increases, in the long run it also faces a reduction.

Fig. 3. Uniaxial compressive strength test.

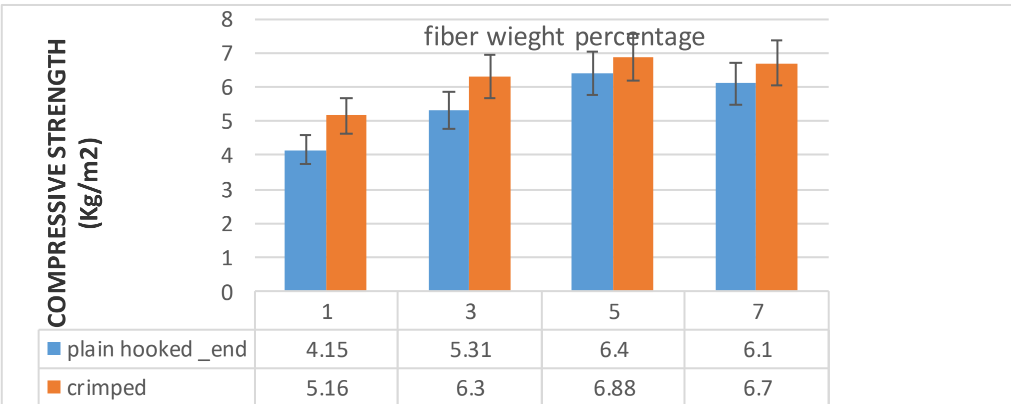

Fig. 4. Changes in compressive strength for different steel fiber content percentages with the aspect ratio (L/D) of 50.

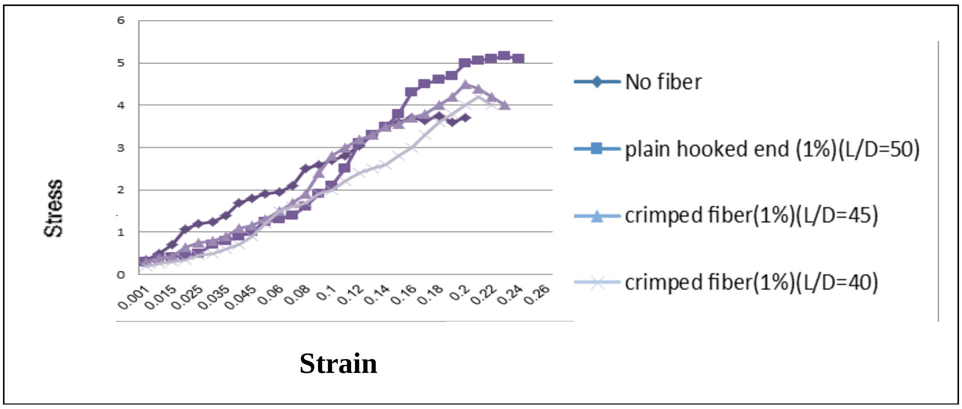

Fig. 5. The stress-strain diagram of reinforced soil with fiber
(equal percentages 1% with L / D 50, 45 and 40)

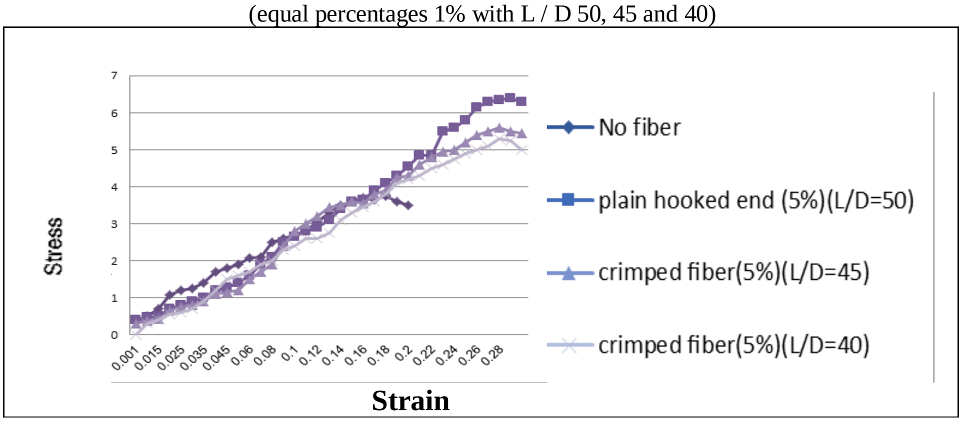

Fig. 6. The stress-strain diagram of reinforced soil with fiber
(equal percentages 5% with L / D 50, 45 and 40)

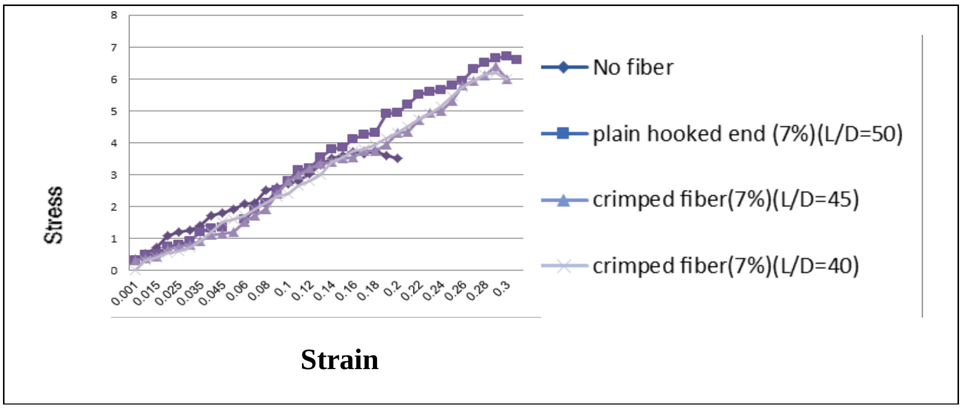

Fig. 7. The stress-strain diagram of reinforced soil with fiber
(equal percentages 7% with L / D 50, 45 and 40)

Figures number 5 to 7 are showing stress-strain diagram. From these figures it can be referred that as more as we add fibers to the soil the stress and strain will increase and this increase will be until we add 5 percent fibers, the soil stress decreases. While strain will permanently increases as a result of unattachment of soil. When we added fibers to the soil the empty spaces will increase and will cause the rise in length changes and te strain.

3.1.2. Fibers with the Aspect Ratio of 45 (L/D)

Table 3 shows the impact of two types of steel fibers with the aspect ratio of 45 and different fiber weight percentages on soil compressive strength. As mentioned in figure 5 for aspect ratio of 45, the addition of steel fibers up to a certain level has positive impact on soil compressive strength, while contrary impacts up to 50% and 60% have been observed for addition of hooked-end and crimped steel fibers respectively exceeding that level.

Table 3. Changes in compressive strength in soil reinforced with fibers with the aspect ratio (L/D) of 45

Compressive strength relative changes for fiber reinforced soil compared to soil with no fibers	**Average compressive strength, Kg/cm^2**	**Compressive strength of three samples, Kg/cm^2**			**Crimped fibers, (%)**	**Plain hooked-end fibers (%)**
0	4.15	4.15	4.08	4.2	-	1
31	4.94	4.98	5	4.85	-	3
50	5.5	5.5	5.6	5.4	-	5
41.8	5.2	5.18	5.33	5.1	-	7
28	4.7	4.7	4.65	4.75	1	-
60	5.88	5.8	5.85	6	3	-
80	6.67	6.9	6.5	6.6	5	-
77	6.58	6.45	6.8	6.5	7	-

Figure 8 shows changes of compressive strength with two types of steel fibers with the aspect ratio (L/D) of 45 and different fiber weight percentages. Comparing figures 4 and 8 leads to the conclusion that steel fibers with the aspect ratio (L/D) of 45 have smaller impact on soil compressive strength than steel fibers with the aspect ratio (L/D) of 50. This reduction in compressive strength is 25% for hooked-end steel fibers and 10% for crimped steel fibers. The same factor is observed on the shape. The coefficient of bearing in the corrugated fiber is more than that of the hook fiber, or, in other words, the bearing coefficient is directly related to the bonding of the soil to the fibrous material (fibrous).

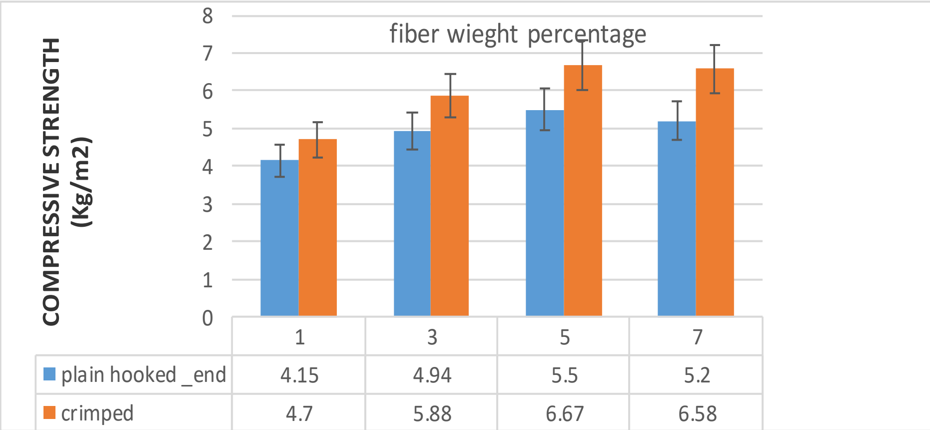

Fig. 8. Changes in compressive strength for different steel fiber content percentages with the aspect ratio (L/D) of 45

3.1.3. Fibers with the Aspect Ratio(L/D) of 40

Table 4 shows the impact of two types of steel fibers with the aspect ratio of 40 and different fiber weight percentages. As shown, these fibers have less impact on soil compressive strength than fibers with aspect ratios of 45 and 50. When the soil is reinforced, it's compressive strength increases up to 45% and 75% respectively with plain hooked-end and crimped fibers.

Table 4. Changes in compressive strength in soil reinforced with fibers with the aspect ratio (L/D) of 40

Compressive strength relative changes for fiber reinforced soil compared to soil with no fibers	Average compressive strength, Kg/cm^2	Compressive strength of three samples, Kg/cm^2			Crimped fibers (%)	Plain hooked-end fibers (%)
5	3.9	3.9	3.8	4	-	1
25	4.6	4.7	4.5	4.6	-	3
45	5.12	5.16	5.2	5	-	5
39	5.116	5.2	5.15	5	-	7
23	4.58	4.65	4.5	4.6	1	-
52	5.34	5.45	5.35	5.2	3	-
75	7.2	7.2	7.3	7.1	5	-
69	6.693	6.68	6.8	6.6	7	-

Figure 9 shows changes of compressive strength for steel fibers with different fiber weight percentages and aspect ratio (L/D) of 40 varying between 15% to 21%. Comparing figures 8 and 9 leads to the conclusion that steel fibers with the aspect ratio (L/D) of 40 have smaller impact on soil compressive strength than steel fibers with the aspect ratio (L/D) of 45. This reduction in compressive strength is 20% for hooked-end steel fibers and 15% for crimped steel fibers. According to the above figure, it can be concluded that steel fibers with a length to diameter ratio of 40 have less compressive strength than lengths of 45 and 50 in diameter, which is why the soil may not be in contact with steel fibers or in other words, it is not well armed to withstand more resistance. In addition, it has a lower coefficient of bearing than the two fibers above.

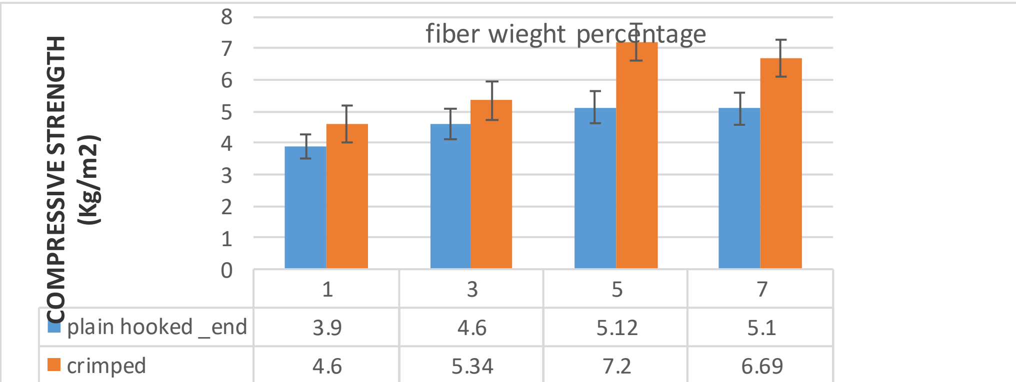

Fig. 9. compressive strength for different steel fiber weight percentages with the aspect ratio (L/D) of 40.

3.1.4. Bearing Capacity Value

When the compressive strength of steel fiber reinforced soil is divided by the compressive strength of soil with no fibers, a dimensionless value known as bearing capacity value is obtained.

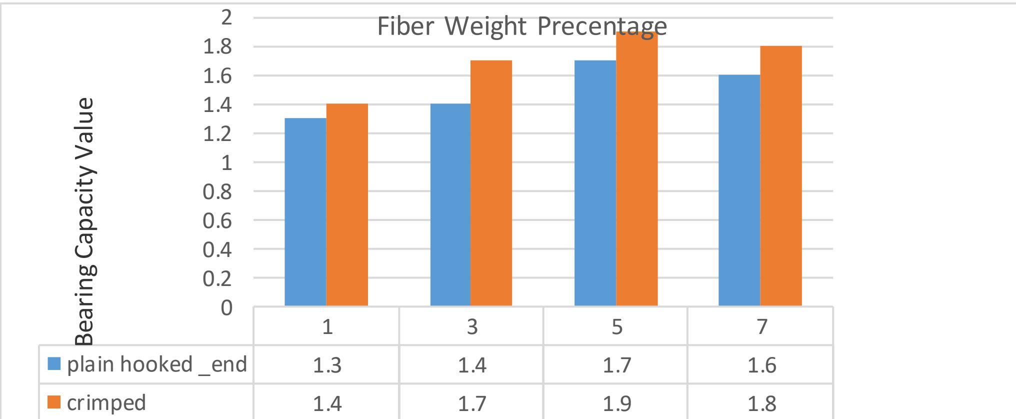

Fig. 10. Changes in bearing capacity value for different fiber weight percentages with the aspect ratio of (L/D) 50.

Figure 10 shows bearing capacity values for different weight percentages of steel fibers. The figure indicates, as in soil compressive strength, the addition of steel fibers to soil up to a certain extent has positive impact on the bearing capacity value. Therefore, the amount of fibers exceeding that extent produces negative impact on bearing value. The bearing value in the above figure is increased with 5% steel fibers, while with 7% steel fibers negative impact is shown. The main reason of this negative effect is the increase of tension in the result of dramatic increase of fibers that causes the samples to modify.

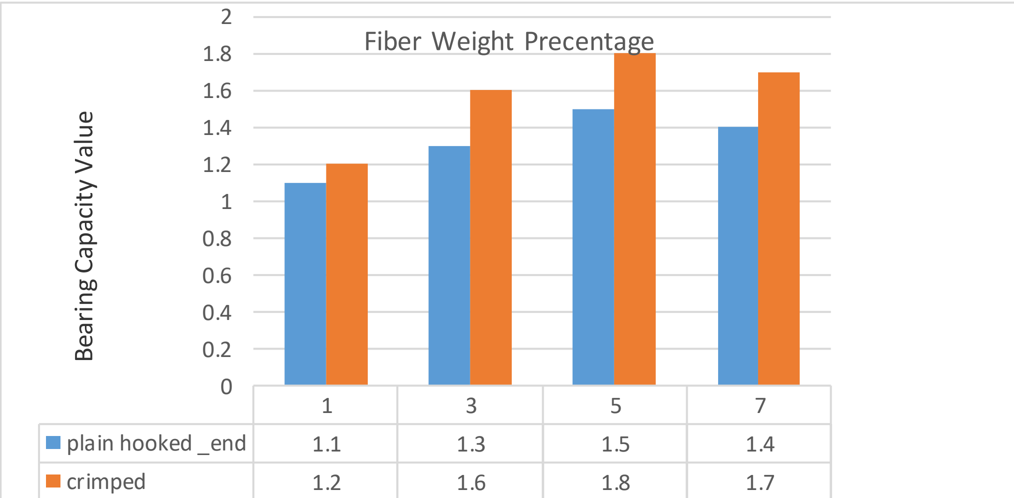

Fig. 11. Changes in bearing capacity value for different fiber weight percentages with the aspect ratio of (L/D) 45.

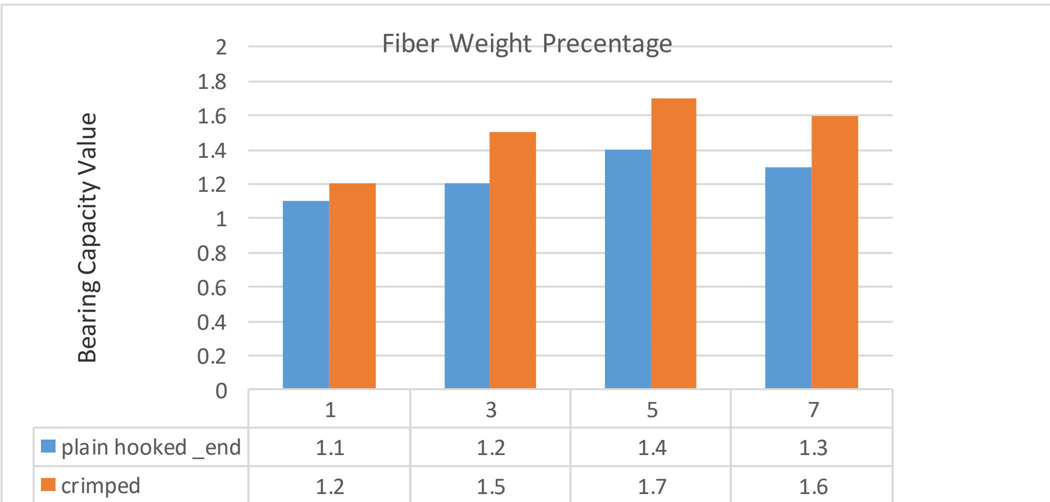

Fig. 12. Changes in bearing capacity value for different fiber weight percentages with the aspect ratio of (L/D) 40.

Figures 11 and 12 show how fiber types and different weight percentages affect bearing capacity value of soil. As shown, 5% crimped steel fibers with the aspect ratio of (L/D) 45 have more impact in increasing bearing capacity value compared to plain hooked-end and crimped steel fibers with the aspect ratio of (L/D) 40.

4. Ductility value

To calculate ductility value, the diameter of the soil sample reinforced with steel fibers is divided by the diameter of the soil sample without fibers. To obtain this value for each option, the average diameter from three tests in the middle of the sample has been used.

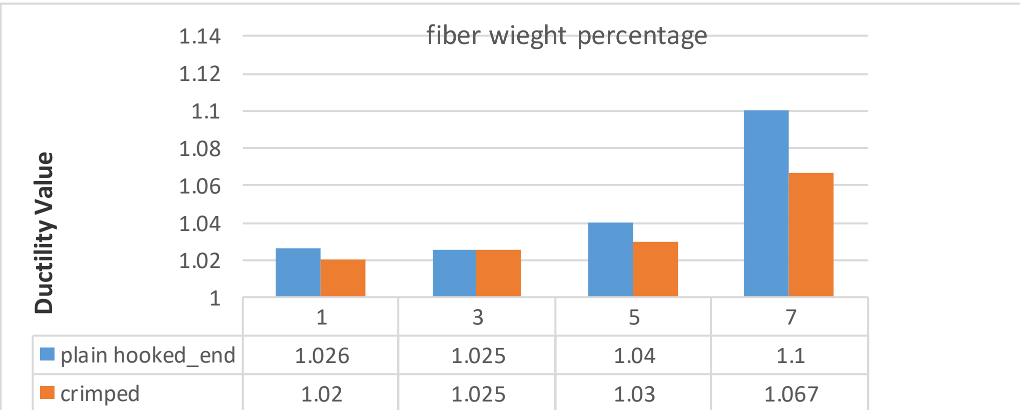

Fig. 13. Ductility value for steel fibers with the aspect ratio of (L/D) 50 in the middle of sample (orangeis crimped and blue is plain hooked _end)

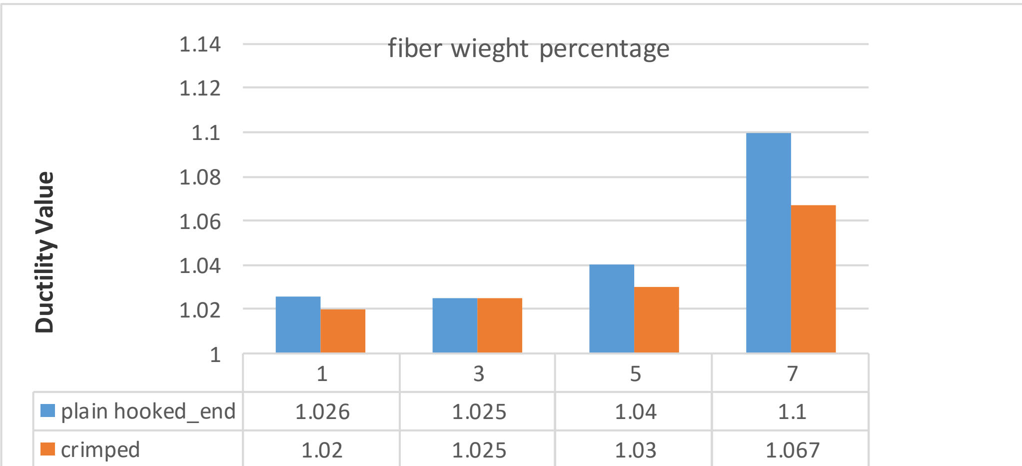

Fig. 14. Ductility value for steel fibers with the aspect ratio of (L/D) 45 in the middle of Sample (orange is crimped and blue is plain hooked end)

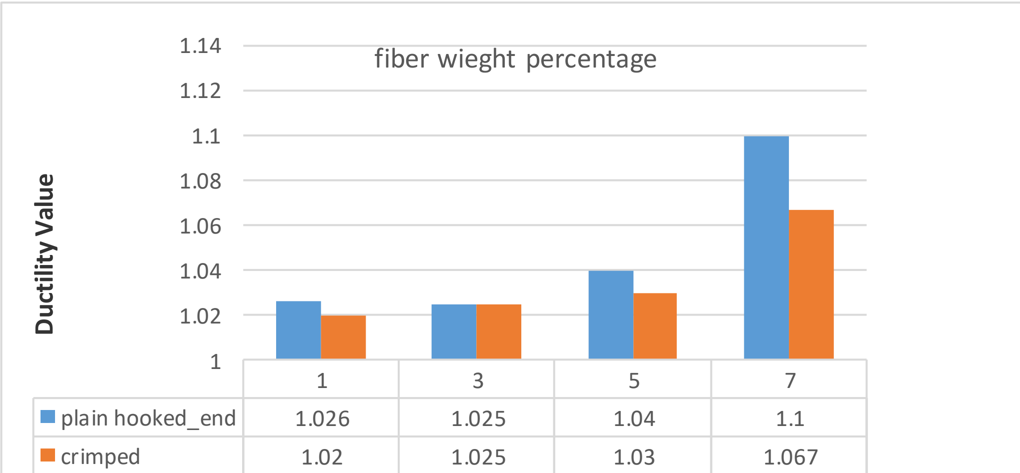

Fig. 15. Ductility value for steel fibers with the aspect ratio of (L/D) 40 in the middle of sample

Figures 13 to 15 indicate that increasing steel fibers increase the ductility value, while reductions occur in the compressive strength and bearing capacity value of samples with additions of fibers more than 5%.

5. Conclusions

The results of the unconfined uniaxial compressive strength tests and examinations on 75 soil samples reinforced with plain hooked-end and crimped steel fibers with different weight percentages of 1, 3, 5, 7 and 40, 45, 50 aspect ratios (L/D) revealed the following effects:

1. The increase in compressive strength for all samples containing steel fibers up to 5% is acceptable, however adding 7% of fibers bring about contrary impact on the compressive strength of the soil. Yet, the increase up to 75% and 93% in samples containing 5% plain hooked-end and crimped steel fibers with the aspect ratio of 50 (L/D) respectively is noticeable.
2. The greater the aspect ratio (L/D) of steel fibers, the more the compressive strength of reinforced soil. Conversely, the greater the aspect ratio (L/D) of steel fibers, the smaller the ductility value.
3. Crimped steel fibers are of greater compressive strength than plain hooked-end steel fibers, while crimped steel fibers allow smaller ductility value.

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