Tensile strength of cement–fiber treated sands

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ABSTRACT: Soil improvement techniques are used to improve the engineering properties of soils. One of the soil improvement methods is the addition of substances such as fibers within cemented sands. In scope of this research, the static behavior of fiber reinforced sand mixed with 3% cement is determined by performing laboratory tests. Conducted laboratory tests are unconfined compression test and flexure tensile strength test. Sand samples are mix with 3% cement and 0, 0.1% and 0.2% fiber. All samples are prepared with modified proctor hammer, mixed with optimum water content and maximum dry density. Cylindrical sample are prepared in 5 layers and prismatic samples were prepared in 3 layers. To study the effect of cure duration on shear strength and tensile stress, samples are tested after 7 days and 28 days. To study the effect of saturation on axial stress and tensile stress sand samples saturated for 1 day following 27 days cure duration. As the fiber ratio and cure duration increase, unconfined axial stress and tensile stress increase. Saturation causes a reduction in unconfined stress and tensile stress.

Keywords: Fiber, cement, sand, undrained stress, tensile stress

1 INTRODUCTION

When the soil conditions are not enough to carry structural loads, the soil properties need to be improved in order to enable safe and economical constructions. Soil improvement techniques are used to improve the engineering properties of soils. Reinforcement is an efficient and reliable technique to modify strength of sandy soils. Stabilization methods can be achieved by the addition of appropriate percentages of cement, lime, fly ash, bitumen, or a combination of these materials to the sandy soil (Perloff, 1976). There are numerous studies on sandy soils which is utilizing additive materials such as glass fiber-Portland cement, rice husk ash, pond ash, fly ash and geogrid. In general, soil reinforcements can be classified in two major categories: (1) ideally inextensible and (2) ideally extensible inclusions (Dermatas and Meng, 2003). Up to now, various studies have been conducted utilizing different additives in combination with cement and lime to improve the strength of sandy soils. Recent research trends in the field of geotechnical engineering and construction materials have focused on cheaper, locally available materials. (Naeini and Mahdavi 2009), (Daniels and Inyang 2003).

In scope of this study, fiber and cement are used as reinforcement to improve the strength of sand. Sand samples mixed with 3% cement and 0, 0.1% and 0.2% fiber are tested in flexural test apparatus and unconfined compression test apparatus. Furthermore, the effect of cure duration and saturation on shear strength and tensile stress are also studied for 7 days, 28 days and 27+1 day cure duration

2 MATERIALS AND TEST APPARATUS

The soil is utilized in this experiment is yellow sand which contains 1% gravel, 68% sand, 29% silt and 2% clay. Its fine grain ratio is 31%. Liquid limit, plastic limit and plasticity index are 33%, 18% and 15% respectively. Therefore, according to USCS the soil is classified as clayey sand (Table 1). Modified proctor test was also performed to determine optimum water content and maximum dry density of pure sand and cemented sand (Table 2).

Table 1. Properties of sand with plastic fine grain

Soil Properties	Values
Specific gravity	2.68
Consistency Limit	
Liquid Limit (%)	33
Plastic Limit (%)	18
Plasticity Index (%)	15
USUC Classification	SC
Gravel (%)	1
Sand (%)	68
Silt (%)	29
Clay (%)	2

Table 2. Modified proctor test results

Soil type	Cement (%)	γ_d max (kN/m^3)	ω_{opt} (%)
Sand with plastic fine grain	0	19.1	12
Sand with plastic fine grain	3	19.1	12.5

2.1 *Cement*

Cement which were utilized as cementing agent for sandy soil is classified as CEM IV/B(P).

2.2 *Kratos synthetic fiber-reinforcement*

The fiber used as the reinforcement is called Kratos Micro Fiber. The properties of fiber are given in Table 3. The fiber in 24mm length was used in this study.

Table 3. Properties of Kratos Micro EN-14889-2 Class 1

Properties	Value	Method/Standard
Density (gr/cm^3)	1.14	ASTM D 792
Length (mm)	6 – 12 – 18 – 24	EN 14889-2
Filament diameter (micro)	27	EN 14889-2
Moisture uptake (equilibirium@50%RH) (%)	2.7	ISO 62*
Tensile strength (MPa)	970	ASTM D 885
Elongation at break (%)	18	ASTM D 885
Elastic modulus (GPa)	5.3	ASTM D 885
Melting point (°C)	256	ISO 11357-3(2011)
Number of filaments/kg (#/kg)	222 million (6 mm) 111 million (12 mm)	
Alkaline resistance **	+	ASTM E 2098

2.3 *Unconfined pressure test apparatus*

Samples were prepared by Modified compaction in 10 cm diameter and 20 cm height. The axial loading speed was 0.4 mm/min. Its load cell has a capacity of 50kN

2.4 *Flexural tensile strength test apparatus*

Instron 5982 Floor Model Universal Testing System with a capacity of 100 kN has been used for flexural tensile tests, Load measurement accuracy: +/- 0.5% of reading down to 1/1000 of load cell capacity option. Up to 2.5 kHz data acquisition rate option simultaneous on load, extension, and strain channels .Speed range of 0.00005 to 1016 mm/min (0.000002 in/min to 40in/min), depending on model. Its load cell has a capacity of 100kN. The residual strength values are calculated at 1 mm deflection and the toughness values are calculated at 3mm deflection. Flexural tensile strength test has been conducted on prismatic samples with 10 cm width, 30 cm length and 10 cm height.

3 EXPERIMENTAL STUDIES

To modify ductility, tensile, undrained and residual strength both unconfined axial loading test and flexure test samples has been prepared by mixing 3 % cement and 0%, 0.1% and 0.2% fiber. The amount of fiber added to the sand is taken as percentage of the dry weight of sand. To understand the behavior of soils that were mixed with fiber as well as cement, two different experiments were conducted. For unconfined compression tests samples with 10 cm diameter and 20 cm height and for flexural tensile strength test prismatic samples with 10 cm width, 30 cm length and 10 cm height were prepared. All samples were prepared with modified proctor hammer, mixed with optimum water content, cylindrical sample were prepared in 5 layers and prismatic samples were prepared in 3 layers. After preparing the samples, samples kept in a moisture curing tank for 7 and 28 days. Moreover, some of soils were kept in a moisture curing tank for 27 and then the samples were completely put in water for 1 day to study the saturated behavior of samples.

Table 4. Tests Methods

Cured Duration	Cement	Fiber ratio (%)	γ_d (kN/m^3)	ω (%)
7 days	3%	0	18.46	11.59
		0	18.91	8.6
		0.1	18.23	12.33
		0.2	18.77	10.1
		0.2	18.79	9.6
27+1 days	3%	0	18.44	13.42
		0.1	18.39	13.71
		0.2	17.5	19.1
28 days	3%	0	18.25	10.8
		0.1	18.95	8.7
		0.2	19.08	8.3

4 UNCONFINED COMPRESSION TESTS RESULTS

Soils were prepared with 3 percent cement and 0, 0.1% and 0.2% fiber ratio and optimum water content due to paramount importance dry density each sample to be equal to maximum dry density each sample must be weighed to have that of modified proctor test. For each and every percentage of cement and fiber 3 samples were prepared to ensure that results of experiment can be assessed with high precision by similar structure. During the experiment deformation of sample was recorded.

Initial step is to study the effect of structure of two samples with 3% cement without fiber which were kept in a moisture curing tank for 7 days. As shown in Figure 1, it can be acquired, the maximum unconfined compression strength, q_u is between 2330kPa to 2087kPa and axial strain at maximum unconfined compression strength is between 1.625% and 1.7%. The results present that the structure of two samples are the same by almost the same results. Figure 1 also shows after unconfined compression value reaches to maximum, it decreases to zero immediately.

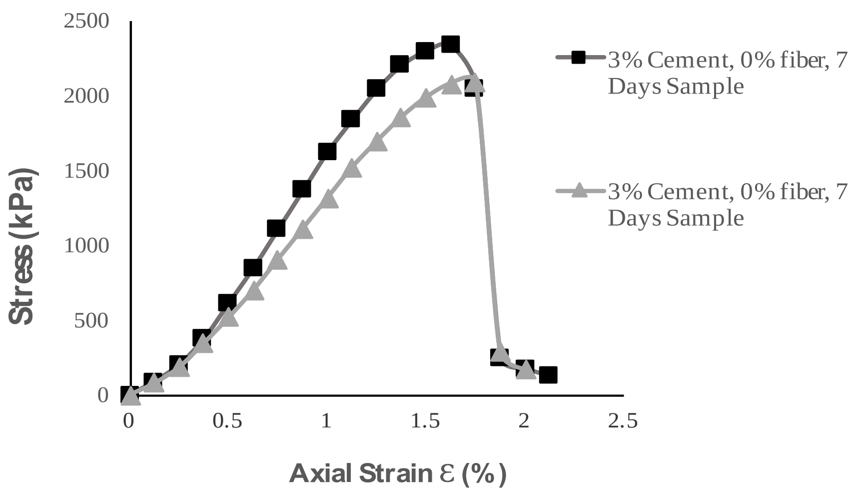

Figure 1. Stress vs. axial strain in sand with 3% cement without fiber, 7 days sample

Second step is to study the effect of structure of two samples sample with 3% cement and fibers. The sample including 0.2% fiber which 7 days kept in a moisture curing tank then they were tested and are presented in Figure 2. From the figure, the unconfined compression strength of samples are almost the same with q_u= 2406 - 2455 kPa at the same axial strain level (1.75%). Axial Stress decreases to 500kPa at 3.5% axial strain level. The structure of samples in this mixture is approximately the same as well. According to Figure 2 there is a major difference between 0 and 0.2% fiber ratio in as much as there is an improvement in the increase of strength after failure.

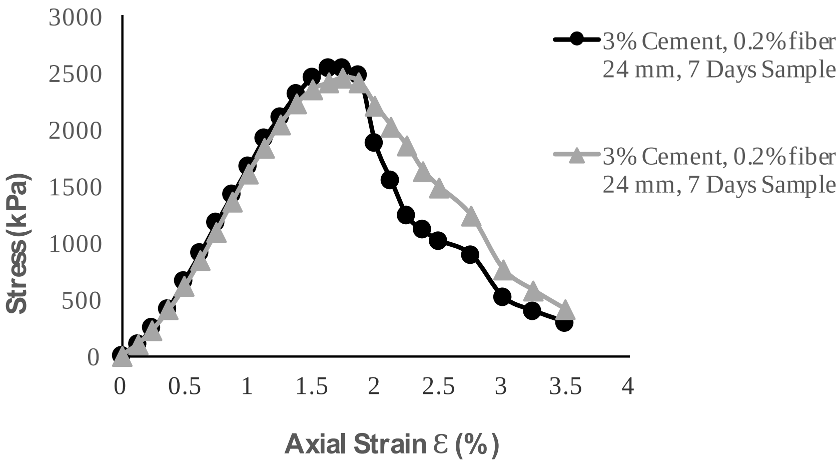

Figure 2. Stress vs. axial strain in sand with 3% cement, 0.2% fiber, 7 days sample

4.1 *The effect of fiber ratio on sand samples cured 7 days*

Initially, samples mixed by 3% cement and 0, 0.1% and 0.2% fiber were kept 7 days in a moisture curing tank to achieve the same moisture content in samples during curing time then samples were tested. Stress versus axial strain behaviors are presented in Figure 3. As shown from the figure, maximum axial stresses are between 2087kPa to 2455 kPa at 1.75% axial strain level. Even though there is not a noticeable difference in the maximum unconfined compression strength between 0, 0.1%, 0.2% fiber ratio for the 7 days cure time, there is a substantial difference shortly afterward failure as the ratio of fiber increases. As the fiber ratio increases samples undergo failure at large strain level while the sample which is not included fiber collapses immediately by following peak stress level.

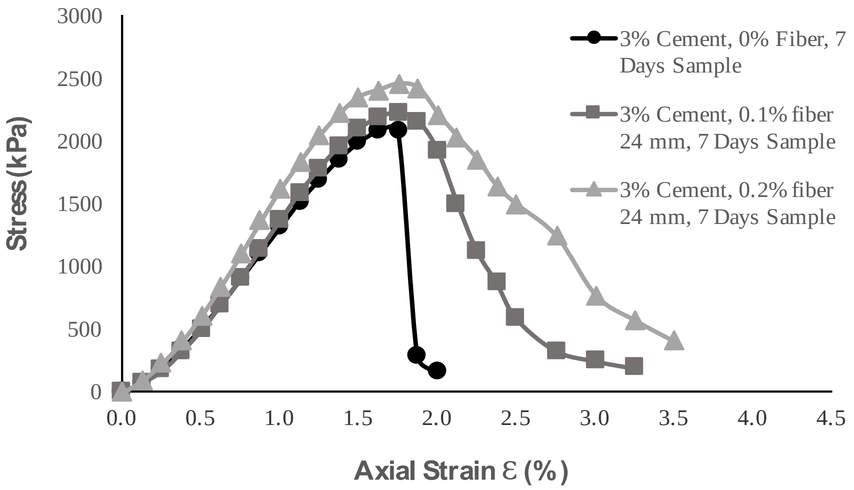

Figure 3. Stress vs. axial strain in sand with 3% cement, 0, 0.1% and 0.2% fiber, 7 days sample

4.2 *The effect of fiber ratio on sand samples cured 28 days*

Samples mixed by 3% cement and 0, 0.1% and 0.2% fiber were kept 28 days in the moisture curing tank then were tested. Results are presented in Figure 4. From the figure, it can be acquired q_u= 3539- 2274 kPa and axial strain in maximum unconfined compression strength is between 1.75% and 2.125%. It is clearly evident that samples with fiber with 28 days cured are radically improved than that of without fiber. Moreover, samples with 0.1% as well as 0.2% either in maximum unconfined compression strength and strength enhanced entirely.

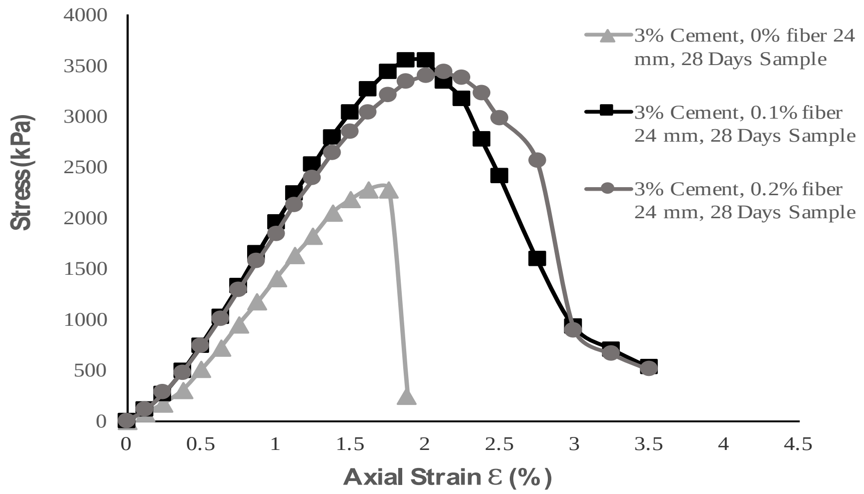

Figure 4. Stress vs. axial strain in sand with 3% cement, 0, 0.1% and 0.2% fiber, 28 days sample

4.3 *The effect of fiber ratio on saturated sand samples cured 27+1 days*

In this step the behavior of saturated sample was investigated. Sample with 3% with 0, 0.1% and 0.2% fiber were mixed then, they were kept 27 days in the moisture curing tank and one day in water which is presented in Figure 5. The maximum axial stress of sand sample which is not included fiber is 1553kPa at 1.2% axial strain level. Samples included fiber with 0.1% and 0.2% have high maximum axial stresses between 1900kpa to 2045kPa at ε_a=1.6% -1.7% axial deformation. As shown from the figure samples in saturated condition show the same stress-strain behavior. Following maximum axial stress as the fiber ratio increases shear stress increases at large axial strain level.

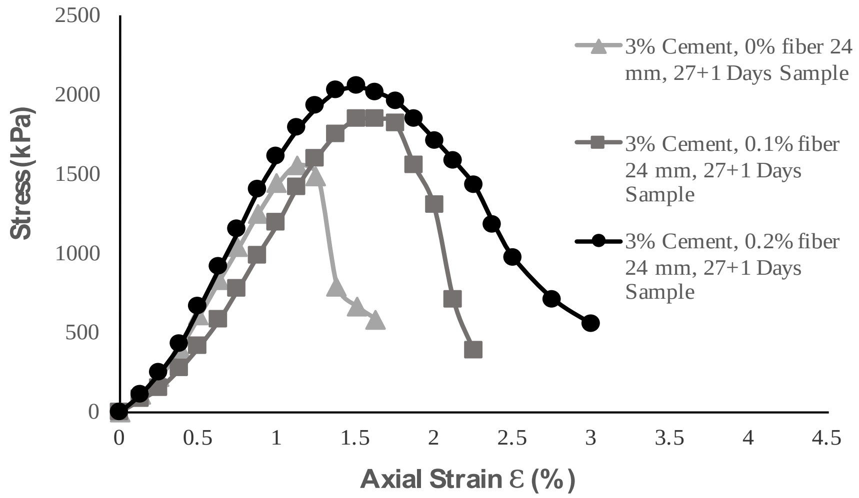

Figure 5. Stress vs. axial strain in sand with 3% cement, 0, 0.1% and 0.2% fiber, 27+1 days sample

5 FLEXURAL TENSILE STRENGTH TEST

The purpose of conducting flexural tensile strength test is to understand the stress-strain behavior of sample with or without fiber.

Figure 6 shows the behavior of samples with 3% cement and 0, 0.1 & 0.2 ratio of fiber cured 7 days. The flexural tensile stress of sample without fiber plummeted down before 1 mm deflection and became zero. On the other hand, sample with 0.1% ratio of fiber flexural tensile strength started from 120 kPa in 1 mm deflection then ended 100 kPa in 3 mm deflection. In sample with 0.2% ratio of fiber, the flexural tensile stress in 1 mm deflection is 270 kPa which despite of 0.1% fiber ratio sample which is almost steady, this sample's flexural stress goes down to almost same as sample with 0.1 % ratio of fiber in 3 mm deflection.

Figure 7 shows the behavior of samples with 3% cement and 0, 0.1 & 0.2 ratio of fiber. To study the effect of saturation these samples are kept in curing tank for 27 days and 1 day in water. As shown in Figure 7, the flexural tensile stress of sample without fiber plummeted down before 1 mm deflection and stress became zero. On the other hand, sample with 0.1% ratio of fiber flexural tensile strength started from 70 kPa in 1 mm deflection then ended 20 kPa in 3 mm deflection. In sample with 0.2% ratio of fiber, the flexural tensile stress in 1 mm deflection is 320 kPa which despite of 0.1% fiber ratio sample which is almost steady, the flexural tensile stress of sample goes down to 150kPa in 3 mm deflection.

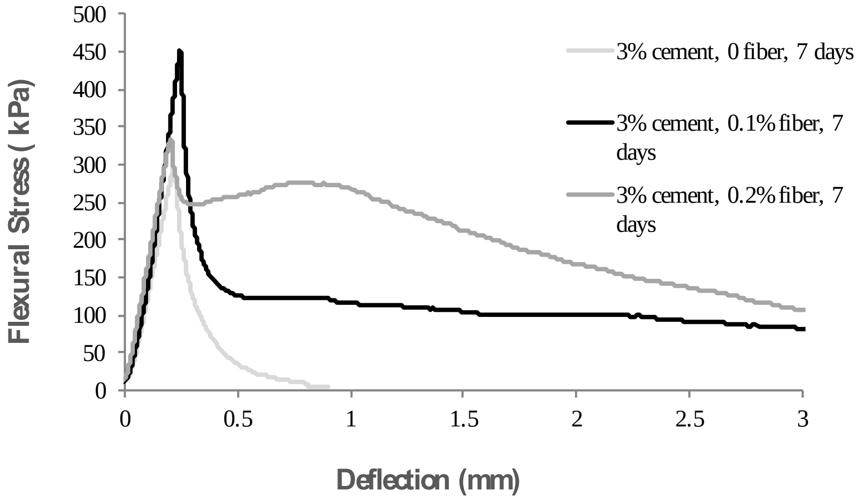

Figure 6. Flexural stress vs. Deflection in sand with 3% cement, 0, 0.1% and 0.2% ratio fiber, 7 days sample

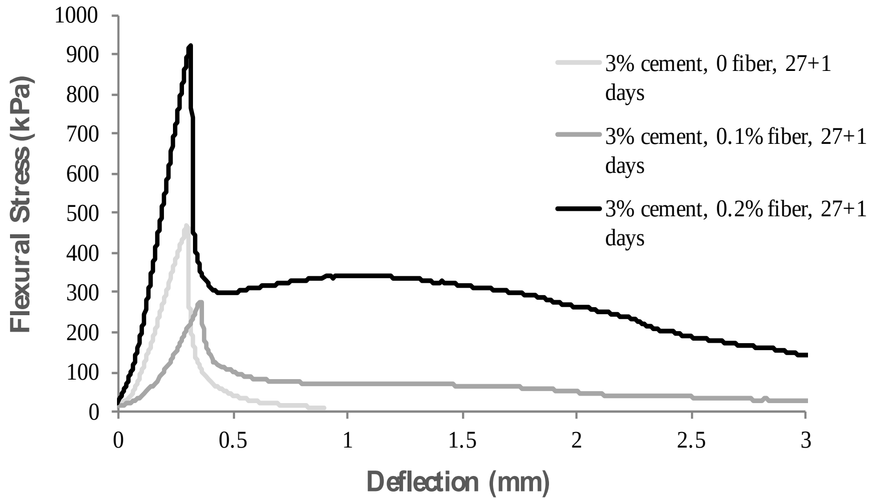

Figure 7. Flexural stress vs. Deflection in sand with 3% cement, 0, 0.1% and 0.2% ratio fiber, 27+1 days sample

The stress-deflection behavior of samples with 3% cement and 0, 0.1 & 0.2 ratio of fiber cured 28 days are given in Figure 8. The flexural tensile stress of sample without fiber plummets down before 1 mm deflection. On the other hand, sample with 0.1% ratio of fiber flexural tensile strength started from 400 kPa in 1 mm deflection then ended 200 kPa in 3 mm deflection. In sample with 0.2% ratio of fiber, the flexural tensile stress in 1 mm deflection is 700 kPa which despite of 0.1% fiber ratio sample which goes down smoothly, this sample's flexural tensile stress goes down to almost 380 kPa in 3 mm deflection.

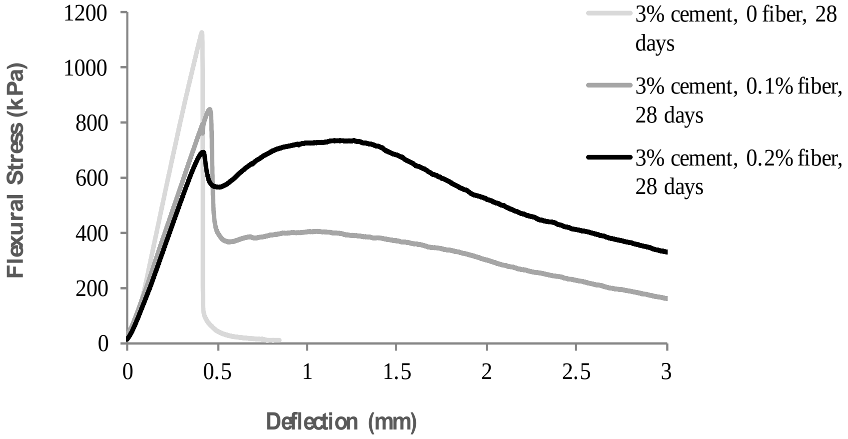

Figure 8. Flexural stress vs. Deflection in sand with 3% cement, 0, 0.1% and 0.2% ratio fiber, 28 days sample

6 EFFECT OF CURE TIME

6.1 *Unconfined compression test*

Figure 9 presents the effect of cured time, saturation and fiber on maximum axial stress of samples mixed with 3% cement and 0, 0.1%, 0.2% fibers. As shown in Figure, the maximum stress of sands increases slightly as the fiber ratio increases at 7 and 28 cure durations. Cure duration influences maximum unconfined shear stresses. There is an improvement in the strength of soil from 0 fiber to 0.2% and higher strength belongs to 0.2% ratio of fiber dosage with 28 days cured time. Saturation of samples causes a reduction in their strength. The maximum shear stress of saturated (27+1) samples reduces below to the maximum stress of samples cured 7 days.

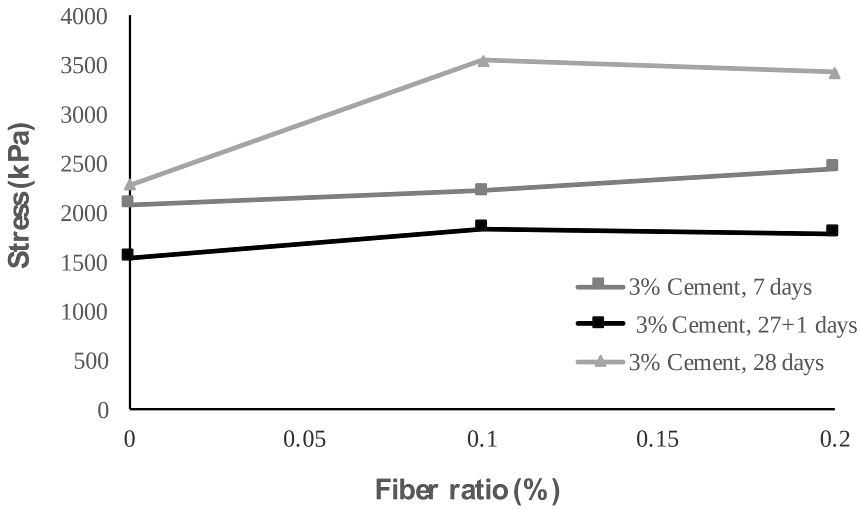

Figure 9. The effect of cure duration on undrained stress

6.2 *Flexural tensile strength test*

Figure 10 presents the effect of cure duration on residual stress. As the fiber ratio increases residual stress increases. The effect of cure duration is limited on residual stress at every fiber ratio. There is no effect of cure duration if cemented sand doesn't include fiber. If the soil is saturated residual stress decreases at every fiber ratio.

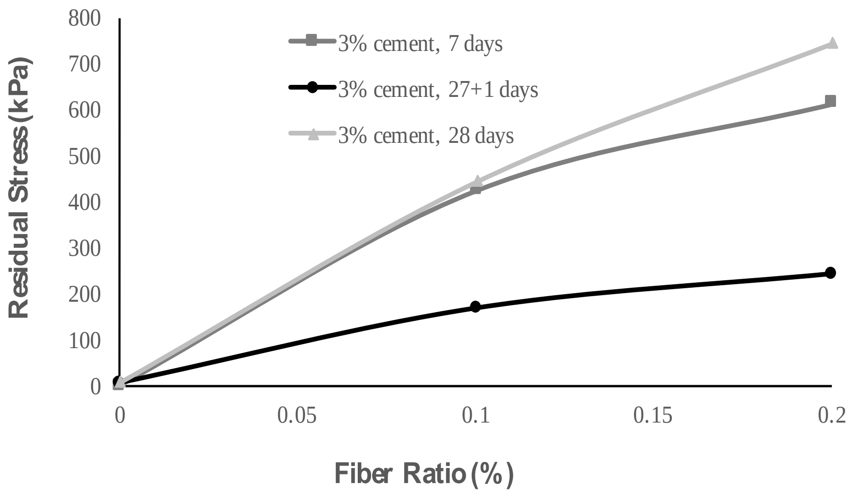

Figure 10. The effect of cure duration on residual stress in flexural test

7 CONCLUSION

In this research the effect of fiber content on stress strain behavior of randomly distributed fiber with 0, 0.1% and 0.2% ratio of fibers and 3% cement reinforced sand is studied in unconfined compression test apparatus and flexure tensile test apparatus. There are improvements as the ratio of fiber increases and curing time affects the strength of sample as well. Cement and fiber inclusion within the sand samples cause an improvement in maximum axial stress and residual stress. If the cemented sand doesn't include fiber, following the maximum axial stress soil loses their strength immediately and collapses at small axial strain level. As the fiber content increases residual stress increases up to 3% axial strain level. The flexural tensile stress of cemented sand sample without fiber plummeted down before 1 mm deflection and became zero. On the other hand, maximum flexural tensile stress of sand samples with 0.1% and 0.2% ratio of fiber increases by increasing fiber content and the residual flexure tensile stress also increase by increasing fiber content. If the soil is saturated maximum stress and residual stress both in unconfined compression test and flexure tensile test decrease at every fiber ratio. Results present when the cement addition without fiber causes brittleness in sand fiber with cement causes ductility of sand.

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