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Effect of Distributing Steel Fibers on Some Properties of Slurry Infiltrated Fiber Concrete

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ABSTRACT

The slurry infiltrated fiber concrete (SIFCON) is nowadays considered a special type of high fiber content concrete; it is high strength and high performance material. This paper investigates the effect of spread steel fiber into the slurry mortar on some properties of SIFCON. According to fiber distribution, two sets were used in this investigation. The first set consisted of randomly distributing fibers inside the slurry. The second set was by placing the fibers in an orderly manner inside the slurry. Crimped steel fibers with an aspect ratio of (60) were used. Two different volume fractions percentage of (7% and 9%) by volume of mold were used in both sets for this study. Also, a w/c ratio of (0.35) and superplasticizer of (1%) by weight of cement was used to ensure the penetration of the slurry inside the fibers. The compressive and flexural strength were conducted on standard cubes (10*10*10) cm and prisms of (40*7*7) cm respectively to find the effect of how the steel fibers were distributed. The results showed that distributing the fibers randomly gave better results than the ordered distribution. The increment percentage in compressive strength and flexural strength were (1.5%, 6.9%, 23%, and 6.5%), respectively, for both sets and both fiber volume fractions (7% and 9%).

Keywords: Slurry infiltrated concrete, spread steel fiber, randomly distributing, ordered distributing, crimped steel fibers.

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تأثير توزيع ألياف الصلب على بعض خواص الخرسانة الليفية المتسربة

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الخلاصة

تعتبر الخرسانة الليفية المتسربة (SIFCON) في الوقت الحاضر نوعًا خاصًا من الخرسانة ذات المحتوى العالي من الألياف، وهي مادة عالية القوة وعالية الأداء. يدرس هذا البحث تأثير انتشار الالياف الفولاذية في الملاط على بعض خواص مادة (SIFCON). تم استخدام مجموعتين وفقًا لتوزيع الألياف في هذا البحث، المجموعة الأولى تتكون من ألياف تم توزيعها عشوائيا داخل الملاط، والمجموعة الثانية كانت بوضع الألياف بطريقة مرتبة داخل الملاط. تم استخدام ألياف فولاذية مجعدة بنسبة باعيه (60). تم استخدام نسبتين حجميتين مختلفين (7٪ و 9٪) حسب حجم القالب في كلا المجموعتين لغرض هذه الدراسة، كما تم استخدام نسبة ماء الى سمنت تبلغ (0.35) و نسبة (1%) من مادة الملدن المتفوقة من وزن السمنت استُخدِمت لضمان تغلغل الملاط داخل الألياف. تم إجراء مقاومة الانضغاط وقوة الانحناء على مكعبات قياسية (10 * 10 * 10) سم ومنشورات (40 * 7 * 7) سم على التوالي لمعرفة تأثير الطريقة التي تم بها توزيع الألياف. أظهرت النتائج أن التوزيع العشوائي للألياف أعطى نتائج أفضل من التوزيع المنظم للألياف وكانت النتائج تمثل نسبة الزيادة في مقاومة الانضغاط وقوة الانثناء (1.5٪، 6.9٪، 23٪ و 6.5٪) على التوالي لكلا المجموعتين و لكلا النسبتين (7٪ و 9٪) على التوالي.

الكلمات الرئيسية: الخرسانة المتسربة، توزيع الألياف الفولاذية، التوزيع العشوائي، التوزيع المنظم، الألياف الفولاذية المجعدة.

1. INTRODUCTION

The real work requirements in the sites in general and the rapid development witnessed by life in various aspects caused an urgent need to find new types of concrete that serve the practical work at a lower cost and faster time. So, theoretical research worked through building materials and sustainable and additives materials of all kinds to develop and find types other than normal concrete, one of these types is Slurry Infiltrated Fiber Concrete (SIFCON).

SIFCON can be considered as advanced material with high performance. Also, it is considered a special type of Steel Fiber Reinforced Concrete **(Giridhar, R., and Rao, P. R. M., 2015)**.

In addition, SIFCON is high strength material containing fiber in high percentage volume compared with steel fiber reinforced concrete. Prof. Lankard proved that one could obtain a material with extremely high strength if the proportion of steel fibers in the cement slurry can be greatly increased, which he termed as SIFCON **(Dagar, 2012)**.

SIFCON could be considered as active alternative building construction materials for applications where concrete or steel fiber reinforced concrete could not perform as per prospective by the operator or when high strength and ductility required. According to **(Soylu and Bingöl, 2019, Parameswaran, V.S., 2009)** SIFCON used in

1- Precast concrete products.

2- Bridge decks.

3- Explosive and seismic resistant structures.

4- Safety concrete applications like safety cabinets, strong chambers etc.

5- Heat resistant applications like furnace lintels and soak-pit covers.
6- Military applications like underground shelters.
7- Primary shielding for nuclear containment.
8- Strengthening, rehabilitation, and repair of structures.
9- Rapid repair work.
10- Massive concrete structures such as marine and long span structures etc. For the previously mentioned application, SIFCON is used due to its great properties such as high strength, crack resistance, ductility, impact resistance, and penetration compared to other materials.

2. LITERATURE REVIEW

(Al-Jalawi, 2009) described the characteristics of high-performance concrete reinforced with a rather high proportion of sliced carbon fibers volume fraction ranging from (1 to 5%). The main benefit of such compounds was comparatively high flexural strength. To keep the cement mix workable, 0.3 w/c ratio with superplasticizer was utilized. A locally available pozzolan based on reactive meta-kaolin was mixed within the silica sand to enhance the characteristics. High modulus carbon fibers (450 KN/mm^2) were also utilized. Flexural strength was determined. The results demonstrated that the specimens failed flexural by a single fracture, despite the fact that the composite's ultimate tensile strength and stiffness improved as the fiber content increased.
(Al-Jalawi and Sara Alaa, 2013) investigated the effect of introducing steel fiber with a volume fraction of (o.5, 0.75, and 1% by concrete volume) with an aspect ratio (100) on the mechanical characteristics of concrete. The experiments were carried out on concrete specimens (cubes and prisms) and steel fibers reinforced concrete subjected to water curing. All of the mixes contained the same volumetric percent of coarse and fine aggregate, as well as the same quantity of water, leading to a consistent W/C of (0.54) for all mixtures. According to the results, the greatest increment percent for compressive strength of steel fibers reinforced concrete samples with volume fractions of (0.5, 0.75, and 1%) and continually cured in water at 90 days was (8, 11.1, and 17.1 %) as compared to reference concrete. The flexural strength of water-cured prisms enhanced as the curing duration increased. At 90 days of curing, the maximum increases were (30.4, 36.8, and 44.3%) for plain and fiber reinforced concrete with volume fractions of (0.5, 0.75, and 1%) treated with water.
(Giridhar, R., and Rao, P. R. M., 2015) used two types of steel fiber with a length of 3.5 cm and 5 cm, with deferent percentages of (4, 6, and 8)% by volume. The results showed that the shortest length fibers' compressive strength was more than that of 5 cm length fibers.
(Salih et al., 2018) used steel fiber of hooked-end having a diameter of 0.07 cm and 3.5 cm length, with an aspect ratio of 50. The fibers are orientated randomly in the slurry matrix. The investigators tested compressive strength for SIFCON on standard cubes of (10*10*10) cm at age of 7 and 28 days for slurry that has no silica fume. Steel fiber was used with percentages of (6%,8.5%, and 11%) by volume. The results show that when the steel fiber volume fraction increases, the compressive strength also increases by (5.2%, 12%, 5.7%, and 8.2%) respectively.
(Al-Abdalay et al., 2020) used micro steel fiber (6 %) by volume; the fiber were randomly distributed in molds by hand. The aspect ratio was 65. Regarding the flexural strength test, the

specimens were tested after curing (7, 28, and 90) days, and the average reading of two samples was taken. It is clear that substantial improvement in flexural strength was about (1.36, 1.45, and 1.54) percentage at the age of (7, 28, and 90) days respectively when the outcomes of SIFCON samples were compared to the results of reference samples. This was due to the large and strong interface between the micro steel fibers and the binder, which increased bond strength and reduced the development of microfractures, resulting in flexural failure.

(Al-Jalawi, 2021) conducted an experiment to explore various mechanical characteristics of Reactive Powder Concrete. Compressive strength, flexural strength, and density are illustrations of these characteristics. The influence of high steel fibers volume fractions (0, 14, 28 % by volume of concrete) layer and (0, 7, 14 % by volume of concrete) random was thoroughly investigated. As a partial replacement by weight of cement, 10% silica fume was used. Also, the Sika ViscoCrete-5930 superplasticizer was used. The experimental study indicated that increasing the volume of steel fibers by 0%, 14%, and 28% (layer) decreased the compressive strength while increasing tensile strength and density. The increase in steel fibers volume 0%, 7%, and 14% (random) decreases the compressive strength while increasing tensile strength and density.

This study aims to clarify the effect of fibers when randomly and ordered distributing and to compare which one gives better results.

3. EXPERIMENTAL WORK

This part explains the materials used for the experimental work. All the experimental work has been executed in the Laboratory of the Civil Engineering Department in the University of Baghdad.

- Ordinary Portland cement (OPC) type 42.5R conforms to the **(IQS No. 5, 2019)** utilize. The physical properties and chemical composition are given in **Table 1** and **Table 2**, respectively.
- Sand conforms to the limits of **(IQS No(45), 1980)** within zone 4 is used in this study.
- Crimped steel fiber with circular cross-section of length 6 cm and diameter of 0.1 cm, with 60 aspect ratio is used. **Table 3** describes the properties of the steel fibers, and **Figure 1** shows its shape.
- Tap water compatibles to the **(IQS 1703, 2018)** is employed for the mixtures.
- Superplasticizer Sika ViscoCrete – 1316 Hi-Tech, high range water reducing (Sika's ViscoCrete polycarboxylate polymer technology (3rd Generation)) is used. **Table 4** shows the superplasticizer properties.

Table 1. Physical properties for OPC.

<table>
<tr><th>Test type</th><th colspan="2">Property</th><th>Test Results</th><th>Limits of (IQS No. 5, 2019) for Ordinary Portland Cement</th></tr>
<tr><td rowspan="4">Physical tests</td><td rowspan="2">Setting time</td><td>Initial (mins)</td><td>140</td><td>Min. 45</td></tr>
<tr><td>Final (mins)</td><td>205</td><td>Max. 10 hrs.</td></tr>
<tr><td rowspan="2">Compressive strength (MPa) at age</td><td>2 days</td><td>23</td><td>≥20</td></tr>
<tr><td>28days</td><td>42.80</td><td>≥42.50</td></tr>
</table>

Table 2. Chemical Composition for OPC.

<table>
<tr><th>Test Results</th><th colspan="2">Property</th><th>Test Type</th><th>Limits of (IQS No. 5, 2019) for Ordinary Portland Cement</th></tr>
<tr><td rowspan="14">Chemical Tests</td><td colspan="2">SiO_2 (%)</td><td>27.04</td><td>Not Limited</td></tr>
<tr><td colspan="2">Al_2O_3 (%)</td><td>4.28</td><td>Not Limited</td></tr>
<tr><td colspan="2">Fe_2O_3 (%)</td><td>4.50</td><td>Not Limited</td></tr>
<tr><td colspan="2">CaO (%)</td><td>59.02</td><td>Not Limited</td></tr>
<tr><td colspan="2">MgO (%)</td><td>2.55</td><td>Max. 5</td></tr>
<tr><td rowspan="2">SO_3 (%) Max.</td><td>$C_3A \leq 3.5\%$</td><td>Not applicable</td><td>2.50</td></tr>
<tr><td>$C_3A > 3.5\%$</td><td>2.48</td><td>2.80</td></tr>
<tr><td colspan="2">Loss on Ignition (%)</td><td>3.46</td><td>Max. 4</td></tr>
<tr><td colspan="2">Insoluble residue (%)</td><td>0.58</td><td>Max. 1.50</td></tr>
<tr><td colspan="2">C_3S (%)</td><td>44.00</td><td>Not limited</td></tr>
<tr><td colspan="2">C_2S (%)</td><td>30.50</td><td>Not limited</td></tr>
<tr><td colspan="2">C_3A (%)</td><td>3.60</td><td>Not limited</td></tr>
<tr><td colspan="2">C_4AF (%)</td><td>11.65</td><td>Not limited</td></tr>
</table>

Table 3. Steel fiber properties.

Type of Fiber	cross-section	Length, l (mm)	Diameter, d (mm)	Aspect ratio, l/d	Density (Kg/m^3)	Tensile strength (MPa)
Crimped	Circular	60	1	60	7870	>800

NOTE: 1 According to the importing company.

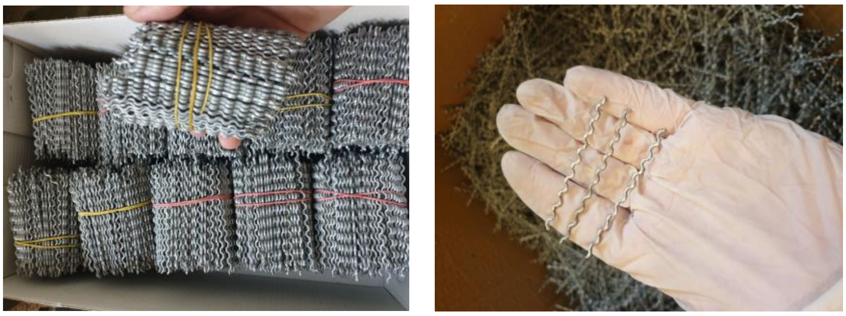

Figure 1. Crimped steel fiber.

Table 4 . Sika Superplasticizer Properties.

Appearance / Color	Light brownish liquid
Specific gravity	1.100 ± (0.005) g/cm^3
PH - Value	4 - 6
Total chloride ion content	Nil
Recommended dosage	1- For plastic Concrete (0.5-1%) by weight of Binder (500-1000gm) for 100 kg cement. 2- For Flow and Self Compacting Concrete (1-1.5%) by weight of Binder (1000-1500gm) for 100 kg cement.
Approvals / Certificates	Sika ViscoCrete – 1316 Hi-Tech meets the **(ASTM C494, 2017)** Type D and G.

NOTE: 2 As the datasheet of the manufacturer.

4. MIX DESIGN AND PROCEDURE

For this work, 1:1 cement to sand by volume, W/C = 0.35 by weight of cement, and the superplasticizer = 1% by weight of cement were used. Two percentages of fibers (7% and 9%) by volume of mold were selected and utilized once with order arrangement inside the molds. The other was randomly arranged for testing compressive and flexural strength. For the SIFCON work, cement and sand have been mixed together in their dry state. In a bowl, the SP has been added to the water and mixed until a homogeneous solution has been obtained. The water with SP was added gradually to the dried materials and mixed by hand until having a good slurry mixture. All the molds were cleaned and oiled before it was cast for the casting procedure. For the cubes (10*10*10) cm and the prisms (40*7*7) cm, a thin slurry layer had first poured in the molds, and the crimped steel fiber was distributed once in order. The other was random; another layer of the slurry was poured over the fibers and infiltrated it. This process was repeated three times for each mold. That means each mold had four layers of slurry with three layers of steel fiber between it. The molds were compacted by lightly knocking on the outer face of the mold to ensure the slurry infiltration without any honeycombs inside the specimen. There was no need to level the top surface of the specimens because the mixture was slurry and took a leveled face on its own. After demolding, all the specimens were placed and immersed in a basin containing tap water at room temperature for the curing process according to **(ASTM C192, 2016)** until testing time.

5. HARDENED CONCRETE TESTS

5.1 Compressive Strength Test

The compressive strength test was conducted according to **(BS EN 12390-4, 2000)** using (10*10*10) cm cubes. This test was conducted using the standard test machine. The average of three cubes was taken as the final result for each group of the two percentages of steel fiber at ages (7 and 28) days.

5.2 Flexural strength test

The flexural strength test was held according to **(BS EN 12390-5, 2000)** using (40*7*7) cm prisms. This test was conducted using the standard test machine; the prims' average was taken as the final result at ages (7 and 28) days.

6. RESULTS AND DISCUSSION

6.1 Compressive Strength Test Result

The cubes (10*10*10) cm prepared for the compressive test were inspected at the age of (7 and 28) days. Two percentages of steel fiber (7% and 9%) were used for both random and ordered distribution. The results show that the compressive strength is affected by way of distributing the fiber (randomly or ordered) for the same fiber volume. From the results shown in **Table 5** and **Figure 2**. It is clear that the compressive strength is higher when the fibers are randomly distributed than if they are arranged in an orderly manner. This is because the compressive strength is affected by the interlocking of fibers. The interlocking of the fibers was more when fibers were randomly distributed than in arranged manner because of the crimped shape of the fibers used. In other words, the overlap between the fibers network, which is crimped, that made it increased the compressive strength of the specimens in which the fibers were randomly distributed.

In addition, when the fiber volume increases, the compressive strength increases according to how fiber has distributed [which is higher in random distribution according to the results shown in **Figure 3** for both curing ages (7 and 28) days. This is agreed with previous researchers such as **(Giridhar, R., and Rao, P. R. M., 2015; Salih et al., 2018b; Soylu and Bingöl, 2019)** and others.

The outcomes of this study are higher than **(Al-jalawi, 2021)** when comparing the compressive strength results due to the fibers type differences.

Figure 4 shows the compressive strength sample after testing**.**

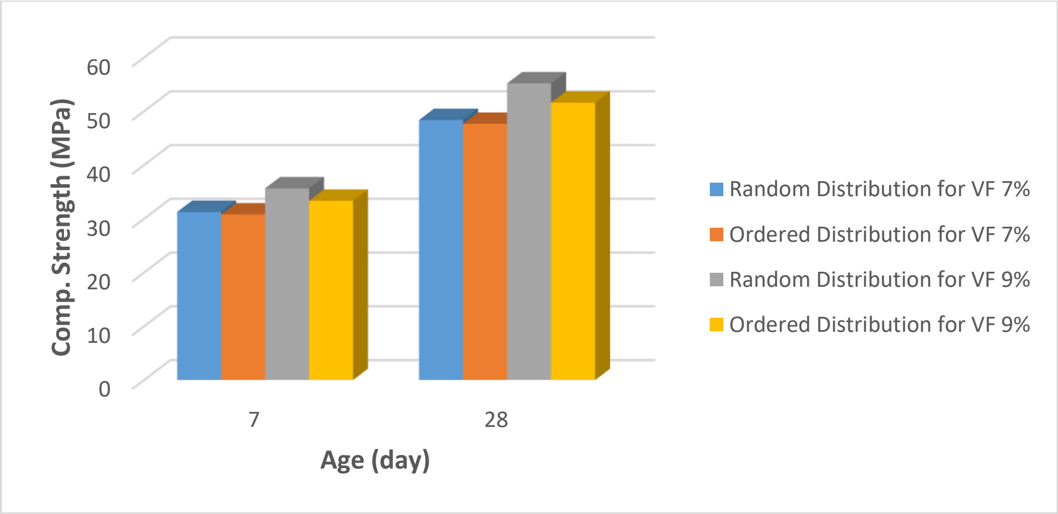

Figure 2. Relationship between Compressive strength and age of curing for (7% and 9%) fiber volume.

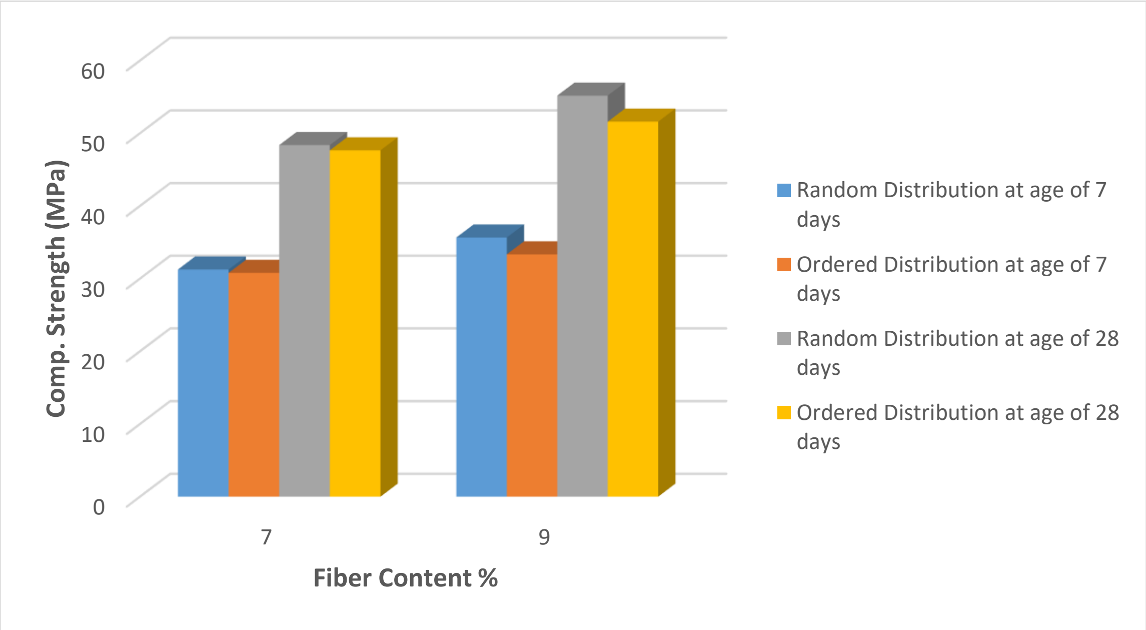

Figure 3. Relationship between Compressive strength and FV% at the age of (7 and 28) days curing.

Figure 4. Compressive strength sample after testing.

6.2 Flexural Strength Test Result

During the flexural test, the specimens showed that fibers do not have any distortion during the rupture of the specimens. They have been separated from the hardened slurry, which declares that the adhesion between the fibers and the hardened slurry has been overtaken. In spite of that, the adhesion was great between the hardened slurry and the fibers. This is agreed with (**Ipek and Aksu, 2019**).

The prisms (40*7*7) cm prepared for the flexural test was tested at age of (7 and 28) days, respectively, with two percentage of steel fiber (7% and 9%) for both random and ordered distribution. The results obtained in **Table 5** show that the flexural strength is influenced by the way of distributing the fiber (randomly or ordered) for a similar fiber volume. From the results shown in **Table 5**, it seems obvious that the flexural strength is higher in randomly distributed fibers than that arranged in an orderly manner. This is due to the highly connected zone between slurry and fibers that enhance the bonding strength and decreases the development of micro-cracks, which drive to flexural failure, and this is agreed with **(Salih et al., 2018)**.

Moreover, the flexural strength increases with fiber volume, according to the way distributing fibers, which is greater in random distribution than in an ordered manner according to the results shown in (**Figure 6**) for both curing ages (7 and 28) days.

When comparing the outcomes of this study with **(Al-jalawi, 2021)**, one can find that the results in Al-jalawi study are better for flexural strength, except for the 9% fibers randomly distributed in this study which gives better results.

Figure 7 shows the flexural strength sample after testing.

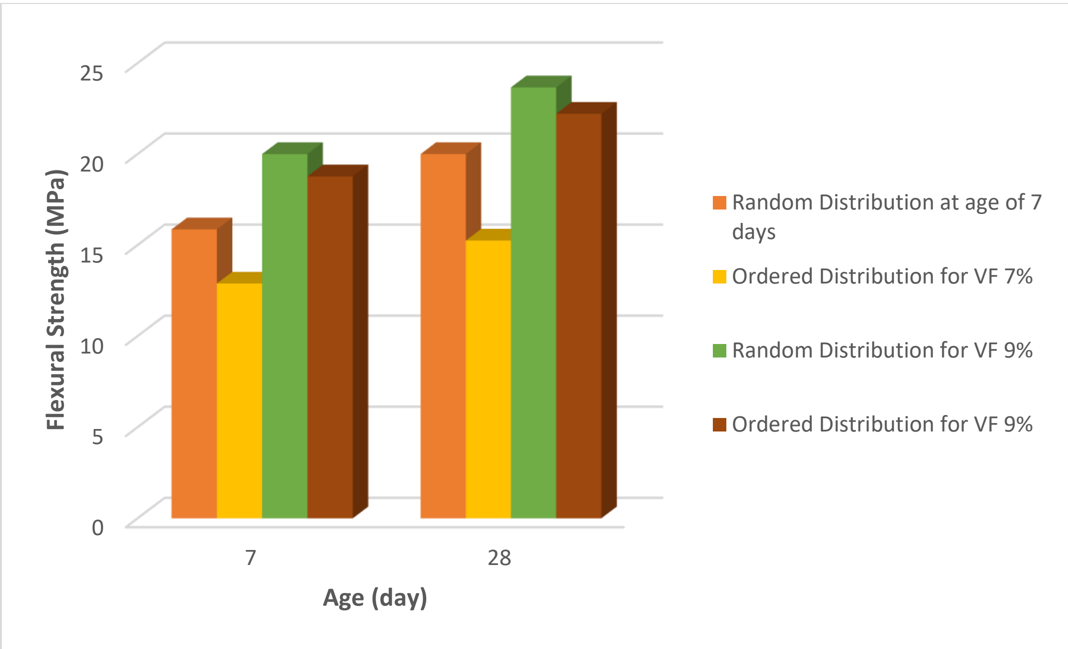

Figure 5. Relationship between Flexural strength and age of curing for (7% and 9%) fiber volume.

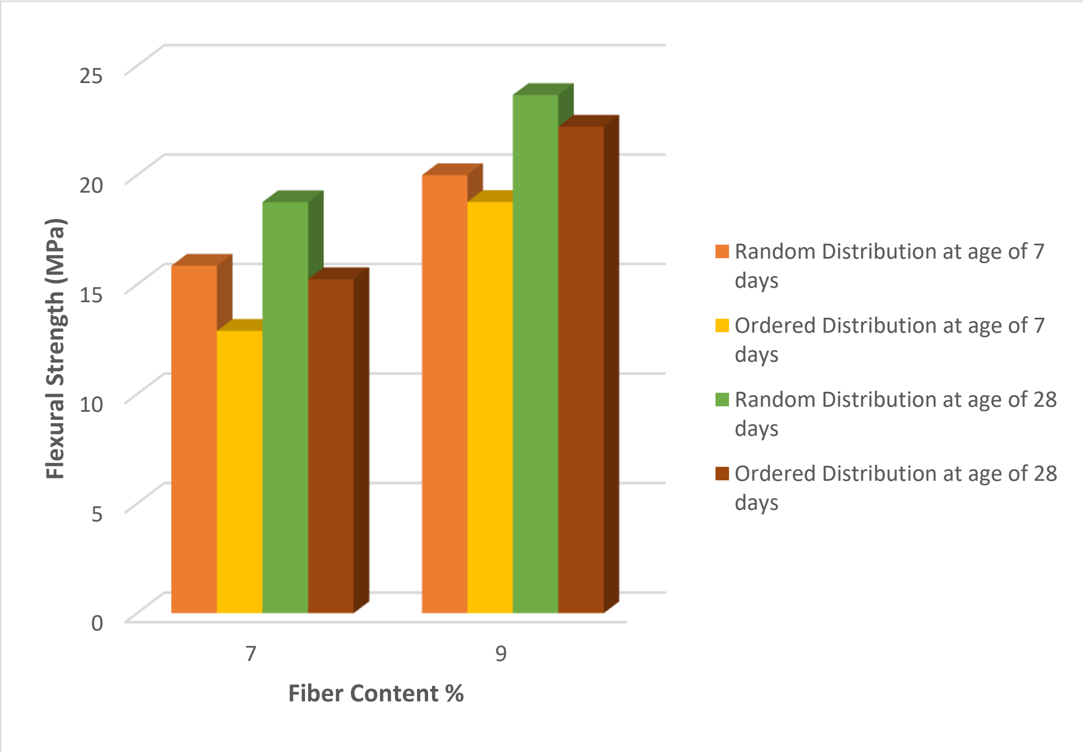

Figure 6. Relationship between Flexural strength and FV% at age of (7 and 28) days curing.

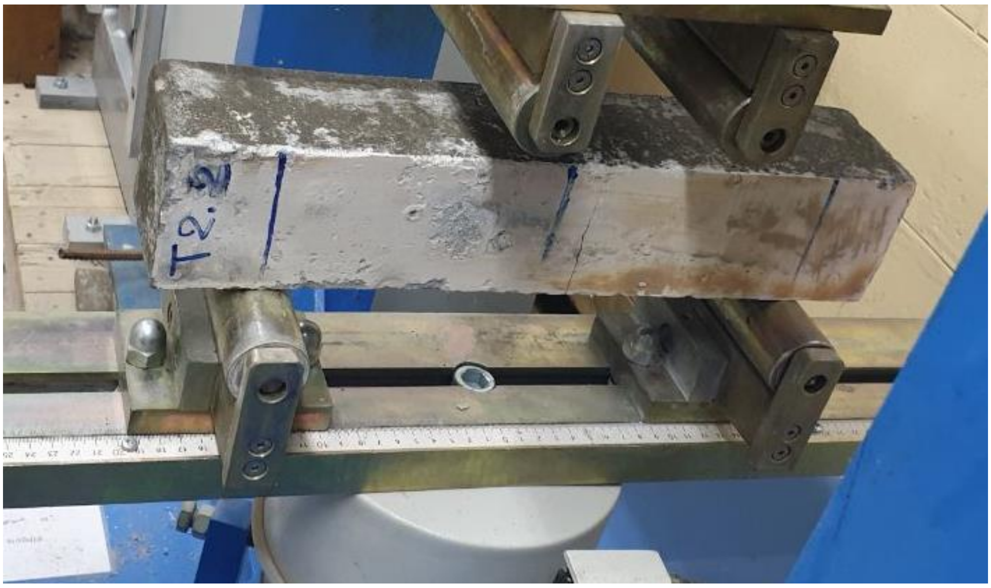

Figure 7. Flexural strength sample after testing.

Table 5. Represent the results of compressive and flexural strength for both sets.

Distribution method	***Random Distribution***				***Ordered distribution***			
Compressive strength (MPa)	**Age (day)**				**Age (day)**			
	7 (day)		**28 (day)**		**7 (day)**		**28 (day)**	
	FV 7%	**FV 9%**	**FV 7%**	**FV 9%**	**FV 7%**	**FV 9%**	**FV 7%**	**FV 9%**
	31.251	35.649	48.366	55.173	30.788	33.334	47.649	51.590
Flexural strength (MPa)	**Age (day)**				**Age (day)**			
	7 (day)		**28 (day)**		**7 (day)**		**28 (day)**	
	FV 7%	**FV 9%**	**FV 7%**	**FV 9%**	**FV 7%**	**FV 9%**	**FV 7%**	**FV 9%**
	15.860	20	18.765	23.663	12.886	18.775	15.246	22.214

7.CONCLUSIONS

In this paper, it was found that:

1- Regarding the compressive strength, it was greater when the fibers were randomly distributed than when they were arranged in an orderly manner. The increment percentage was (1.5% and 6.9%) for both sets and both ages (7 and 28) days, respectively. That means the compressive strength depends on the method the fibers are arranged within the specimens and the fibers volume content in them.

2- For the flexural strength, the results showed that when the fibers were randomly distributed, it gave a higher flexural strength rather than distributed in an orderly manner, the increment percentage was (23% and 6.52%) for both sets and both ages (7 and 28) days respectively. That means the method of arranging fibers within the specimens affected the flexural strength and the fibers volume content in them.

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