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Original Research

INFLUENCE OF STEEL FIBRES OF CRIMPED AND HOOKED-END SHAPE ON THE MECHANICAL PROPERTIES OF PORTLAND CEMENT

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Abstract: Cement mortar without fibers might crack due to shrinkage or volume changes. Cracking in cement mortar leads to elastic deformation. The development of these cracks causes elastic deformation of cement mortar. This study examined the influence of two steel fibers' geometrical forms (crimped and hooked with just one end) in different amounts by volume (Volume fraction = 0.25%, 0.5%, and 0.75%) on the cement mortar's mechanical features. Among the characteristics were splitting, compressive as well as flexural strength. The samples were prepared, poured into cubic molds for compressive strength testing cylindrical molds used for splitting strength testing, and prismatic molds for flexural strength testing, and processed at various times 3, 14, and 28 days before the tests. According to the findings, the highest increase was obtained after adding 0.75% of crimped fibers, the compressive strength increased by 13.3 %21.29%, and 44.8%, for 3,14.28 days respectively, and split tensile strength increased by 66.17%,68.9%, and 79.48% for 3.14 and 28 days respectively and flexural strength increased by 72 %,91% and 92% for 3.14 and 28 days, respectively.

Keywords: *Portland Cement; Mechanical Properties; Compressive Strength; Splitting Tensile Strength; Flexural Strength; Crimped Steel Fiber; Hooked-End Steel Fiber; Fiber Geometry*

1. Introduction

Cement mortar is a widely utilized building material; its tensile strength is lesser when compared with its compressive strength. Cement mortar applications are limited because of the brittle fracture characteristics; this can be avoided by adding a small content of short and random fibers for instance glass, steel, natural, and polymer. Mortar has some disadvantages that include brittleness, low tensile strength, high porous, and low post-cracking capacity. The above deficiencies of ordinary mortar are avoided with innovative materials which have unique properties. Fiber Reinforced Mortar is a new composite material that uses short discrete, equally distributed fibers so that it will enhance engineering features such as flexural strength, fatigue resistance, and impact and eliminate temperature as well as shrinkage cracks [1]. By utilizing fibers, fracture development will be inhibited and a quick, brittle failure will be transformed into a slow, stable fracture with elasticity as well as increased energy absorption capacity before failure [2]. Steel fiber offers numerous, including high elastic modulus, tensile strength, and stiffness. Steel fiber reinforced Mortar (SFRM) has excellent flexural and tensile properties [3]. The reinforced function of steel fiber is mostly

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affected by fiber geometry and content as well as the strength of the matrix [4]. There are several different types of reinforcing fibers. Their cross-sections occur in a variety of forms, including irregular, circular, rectangular, half-round, and round. They are available in different lengths and can be straight or curved [5]. Typically, a fiber's length falls between 12.7 mm and 63.5 mm. The 0.45 to 1.0 mm range is the most common range for fiber diameter. [6].Several investigations caused the development of different fiber geometries to improve the fiber-mortar bond. Dahake and Charkha [7] tested fiber-reinforced concrete specimens that contained different shapes of steel fibers (crimped and hook steel fibers) with 30 mm lengths. The findings revealed the compressive strength increased by 46.6 Mpa for crimped steel and by 53.63 Mpa for hook steel fiber and flexural strength increased by 7.603 Mpa for crimped steel fiber and 7.629 Mpa for hook steel fibers. Byung Hwan Oh [8], according to their research, which looked at the mechanical properties of cement mortar-reinforced steel, these results indicated a rise in strength from 6% to 17 % for compressive strength and 14% to 49 % for split tensile strength, and 25% to 55 % for flexural strength, respectively. Haneen A. Hamed and Zinah W. Abass [9] examined the effect of hook steel fiber on the mechanical properties of concrete. The test results indicate superior properties of concrete including hooked-end steel fiber, as compared with plain specimens, the split strength and flexural strength are 10.14 Mpa and24.89 MPa, respectively for concrete containing 8% hooked-end steel and 9.1Mpa and 17.51 MPa for plain specimens. This study attempts to investigate a few of the mechanical characteristics of cement mortar. after the addition of steel fiber in crimped and hook forms, as well as study the effect of fibers' volume fractions and curing time on these composites.

2. Experiments and Tests

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (Krista Company) was employed in this study. The chemical and physical parameters of cement are listed in Tables 1 and 2. This test of cement findings complies with Iraqi specification limits IQ.S. 5:2019 [10].

Table 1. The physical composition of cement**.**

Test	Results	IQ.S. 5:2019 limits
Fineness (cm^2/g)	4678	>2800
Setting time		
Initial(minute)	120	>45
Final(hr)	3:50	>10
Compressive strength (N/mm^2)		
2 days	25	>20
28 days	43	>42.5

Table 2. Chemical composition cement

Test	Result%	Iraqi Specification limits
Al_2O_3	6.71	
SiO_2	18.14	
Fe_2O_3	2.9	
SO_3	2.09	<2.8
CaO	60.47	
MgO	1.28	<5
C_3A	12.88	
l.o.i	2.72	<4
IR	1.25	
CL	0.009	

2.1.2. Sand

Al-Ekhaider sand of 1.18 mm maximum size is used as fine aggregates. The obtained findings indicate that the sand sieving and the content of sulfate are within Iraqi specification limits No.45/1984) [11]. Table 3" presents the results of the analysis of the sieves procedure.

Table 3. The results of the sieve analysis procedure.

Mesh Size(mm)	%Passing By Weight	Iraqi Specific Limit
1.18	59.7	55-90
0.60	39.3	53-59
0.30	12.4	8-30
0.15	2.28	0-1
Percentage Of Salt%	0.114	≤0.5

2.1.3. Steel fibers

Steel fibers added to mortar enhance mechanical properties and ductility. Two geometries of fibers, crimped fibers and hooked ends fibers with 30 mm length and 36 aspect- ratios employed in this study. For each geometry, three various fiber volume fractions were added in three mortar mixes; 0.25, 0.5, and 0.75% by mortar volume. Fig.1 and Tables 4 and 5 show the steel fiber used in this project.

Table 4. Properties of steel fibers

Properties	Description
Shape of fiber	Crimped fiber, hook-end fiber
Density	7900 kg/m^3
Modulus of elasticity	200 Mpa
Tensile strength	500-2000 Mpa

Table 5. Characteristics of steel fibers **[12]**

Chemical Composition of Steel Fiber	Percentage%
S	0.009
Mn	0.36
P	0.01
Si	0.065
C	0.074

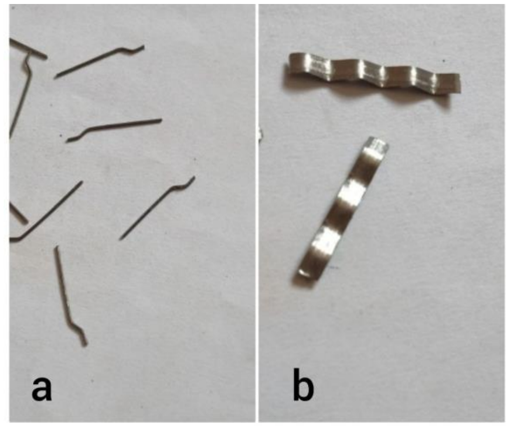

Figure 1. Shapes of steel fiber used (a) hooked-end steel fiber, and (b) crimped steel fiber.

2.1.4 Superplasticizer

As per ASTM C494 [13], Glenium 54 was utilized to improve workability. The properties of the plasticizer are shown in Table 6.

Table6. Properties of superplasticizer

Property	Description
Relative density	1.07
pH	5-8
Alkali Content	0.26%

2.1.5 Water

Water plays an important role in chemical reactions with cement, making it a vital component of mortar. Water from the tap had been employed for mixing as well as curing purposes.

2.2. Mortar Samples Preparation

Mortar was made by using a 1:2.75 cement/sand ratio and a 0.33 water/cement ratio. Two sets of mortars reinforced by steel fibers were created. The first set was reinforced by crimped steel fibres and the second with hooked-end fibres. Each series (crimped and hooked-end) was added with three percentages (0.25, 0.5, and 0.75) % by volume. After mixing, strengthened mortar was poured into cast iron cube molds of (50) mm dimensions for the compressive strength test, (40x40x160) mm prismatic steel molds for the flexural strength test, and (50x100) mm cylindrical steel molds for the splitting test. The total number of specimens (189) that were de-molded and cured at room temperature for 3, 14, and 28 days in the water tank. Fig.2 shows the shapes of the specimens for each test.

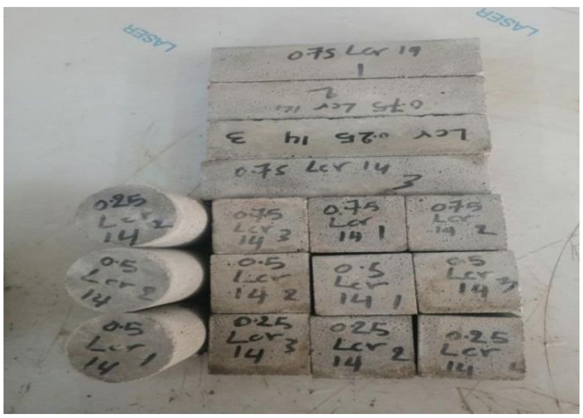

Figure 2. Samples shape molded.

3. Tests Experimental Results

3.1. Compressive Strength Test

The compressive strength test was estimated using 50-mm cubes, following ASTM C109-02 [14]. This test was done on the mortars with a 200KN compression machine.

Fig. 3, 4, and 5 illustrate the impact of fiber geometry and volume fraction on compressive mortar at 3, 14, and 28 days respectively. As fiber content increases, compressive strength gradually increases, The reason for this is the ability of steel fibers to enhance the bonding strength with cement matrix also helps to reduce the occurrence of cracks [15]. The highest compressive strength was found in the mortar that contained crimped fibers, while that with hook fiber indicated the least results. The compressive strength rose by 13.3%, 21.29%, and 44.8% at 3, 14, and 28 days when 0.75% crimped fibers were added. With the incorporation of 0.75% hook fiber, the compressive strengths increased by 11.4%, 15.21%, and 40.35% at 3, 14, and 28 days respectively. This might be due to varying bonding strengths associated with the shape of fibers. The fiber-matrix interface's strength is mostly due to chemical bonds, anchoring, and friction. Crimped fibers may give stronger mechanical contact than hooked end fibers. [16, 17].

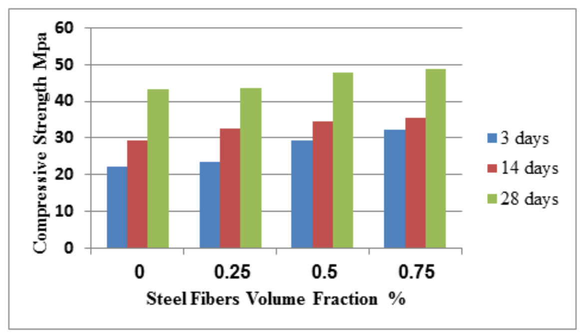

Figure3. The impact of crimped fiber on mortar's compressive strength.

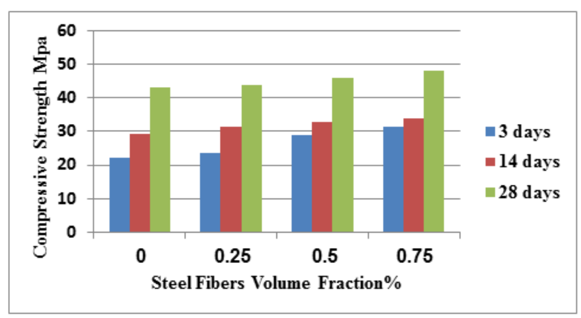

Figure4. The impact of hook fiber on the mortar's compressive strength.

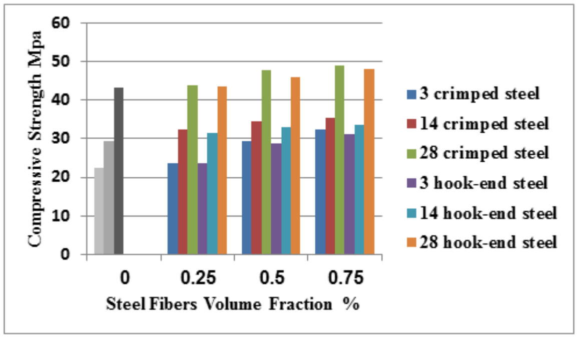

Figure 5. Comparison between crimped and hook steel fiber on mortar compressive strength.

3.2 Splitting tensile strength

The test was conducted as per ASTM C496 [18]. The mortar cylinder is 50mm in diameter by 100mm in height was used. The splitting strength test was calculated by using a digital compression machine with 200 KN capacity.

The relationship between splitting strength and volume fraction with the various steel fiber forms is shown in Fig. 6, 7, and 8. Splitting tensile strength enhanced continuously as Vf rose from 0 to 0.75% [19], increasing the number of fibers can decrease the average distance between them. which made more fibers support stress that resulted in multi-cracks. [20]. The results of the tests demonstrated that crimped fiber had the highest reinforcing impact on splitting tensile strength due to the surface of crimped fiber having a larger interface bonding force than hook fiber [17]. The best percentage of steel fiber added is 0.75%, where increased crimped steel fiber by 66.17%,68.9%, and 79.48% for 3,14 and 28 days respectively, and the hook steel fiber increased the splitting tensile strength by 63.60%, 66.01% and 77.35% for 3,14 and 28 days respectively.

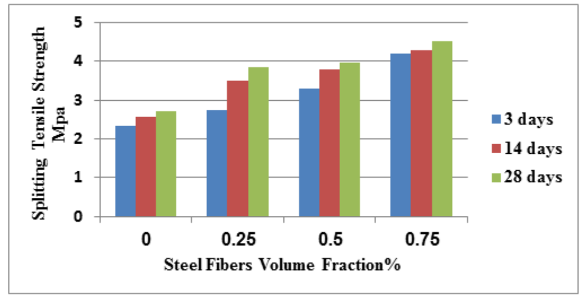

Figure 6. The impact of crimped fiber on mortar's splitting tensile strength.

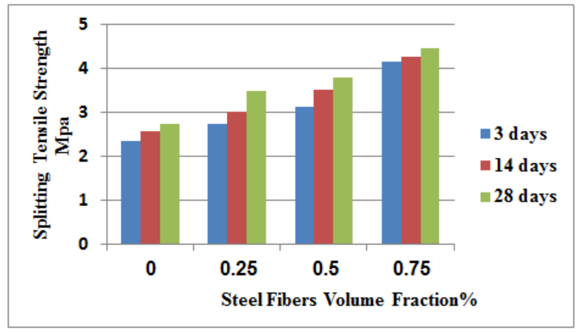

Figure 7. The impact of hook fiber on mortar's splitting tensile strength.

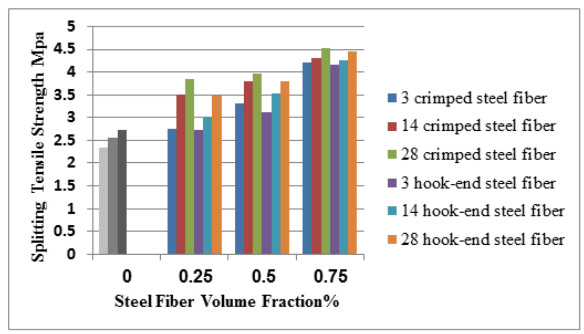

Figure 8. Comparison between crimped and hook steel fiber on splitting tensile strength of mortar.

3.3 Flexural strength

The flexure strength test was estimated using (ASTMC348-08)[21]. A flexural strength test was conducted on (40x40x160mm). prisms with a clear span of 100mm, loaded at one spot with a compression machine.

The effect of fiber shapes and volume fractions on the mechanical properties of mortar is shown in Fig.9, 10, and Fig. 11, As seen in the figures for the fiber shapes, the use of fibers in the mortar mixture at fractions of 0.25%,0.5%, and 0.75% Vf enhanced the flexural strength due to more fibers are present on the crack surfaces, resulting in a greater bonding area between the fibers and the matrix [22]. The figures also show that the mortar exhibiting crimped fibers had the highest flexural and the lowest flexural strength was found in those containing hook fiber. This was explained by the fact that various bonding qualities depended on the geometry of the fibers [9]. The best percentage of steel fiber added is 0.75%, where increased crimped steel fiber 72%, 91%, and 92% for 3,14 and 28 days respectively, and the hook steel fiber increased the splitting tensile strength by 65%,66%, and 76% and for 3,14 and 28 days respectively.

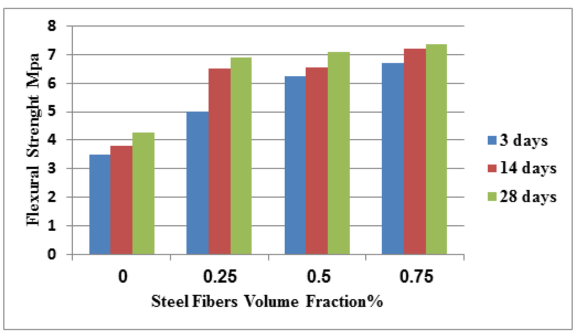

Figure 9. The impact of the crimped fiber on mortar's flexural strength.

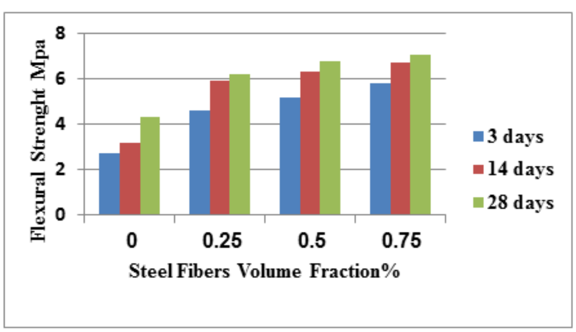

Figure 10. The impact of hook fiber on mortar's flexural strength.

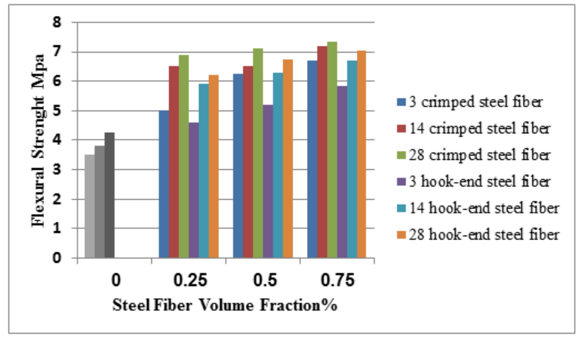

Figure 11. Comparison between crimped and hooked steel fiber on mortar flexural strength.

4. Conclusions

In this research, the addition of steel fibers (crimped steel fibers and hook with one end steel fiber) to the cement mortar can significantly improve their compressive, flexural, and splitting strength when compared with plain mortar. Based on the findings, the mechanical characteristics of the cement mortar improved with the increase in the fiber's volume fractions and the optimum value of the steel fiber added into the cement mortar was when the volume fraction was 0.75% and after 28 days of curing in the water tank. Using different forms of steel fibers significantly enhanced fiber-matrix connection strength. With the identical fiber length and volume fractions, the strength of mortar followed the order of crimped steel fiber higher than hook steel fiber based on the results. The results revealed that incorporating steel fibers increases compressive strength, splitting, and flexural strength. Also, increasing the mortar curing days increases the strength of all steel fiber shapes and fractions.

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Abbreviations

Vf	Volume fraction
SFRM	Steel fibers reinforced mortar

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Nada Hamad Khalaf is a master's student and Yasir Khalil Ibrahim and Sahib Mohammed Mahdi supervised the findings of this work.

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