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Research Article

Investigating The Mechanical Behavior of High-Strength Concrete Reinforced with Hooked Steel Fibers

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Keywords

Ultra-High-Performance concrete,
Steel fiber,
Hooked steel fiber,
Mechanical engineering
Durability.

Abstract

The engineering properties of high-strength concrete are significantly different from those of ordinary concrete, and as a result, this concrete has become popular in a variety of applications, including the construction industry, particularly for tall buildings, bridges with long spans, and precast members. Reinforcing high-strength concrete using fibers is a common method for increasing ductility without losing strength. In this study, steel fibers were employed to replace 1, 1.5, 2, and 2.5 percent of the total volume of concrete, and a total of 5 mixed designs were conceived and constructed. The findings showed that the addition of steel fibers up to 2% by volume boosted the compressive strength and decreased at 2.5% by volume. The incorporation of steel fibers has diminished the mixes' durability.

1. Introduction and literature review

In order to create isotropy conditions and to reduce the brittleness and brittleness of the concrete body as much as possible, in the last few decades, thin and relatively long fibers are used, which are homogeneously dispersed throughout the volume of concrete. [1]
High-strength concretes have also been considered in the construction of bridges. The first bridge using this type of concrete was built in Canada in 1997, and in 2006 in the United States of America, this type of concrete was also used in the construction of a bridge on the highway. , used. High strength concrete can also be used in architecture and artistic structures. [2] Improving the mechanical characteristics and durability of these concretes may reduce costs by lowering the cross-sectional area of members, hence reducing the number of consumables and labor costs, which is crucial from an economic standpoint in the construction industry. High initial cost has hampered the widespread usage of high-strength concrete, although research is now being performed to make concrete with a lower beginning cost. Today, this concrete is known as Ultra-High-Performance Concrete or UHPC because to its unique qualities. This form of concrete was referred to as High Strength Concrete (HSC) or high strength concrete due to its thick structure and very high mechanical resistance, which was significant to researchers throughout the past two decades. Since the beginning of the 21st century, Ultra-High Performance Concrete (UHPC) has progressively gained popularity owing to the rising role of pozzolans and the decrease in cement-related environmental pollutants. With the passage of time and over the previous decade, the expectation of large resistances, as expressed by researchers such as Yu and his colleagues in their study, has steadily dropped, and the resistance of 110 MPa has been validated in reputable journals indexed under this title. [3]
A very low water to binder ratio is used in high strength concrete. The lowest value equal to 0.08 has been proposed by Richard [4], which of course does not guarantee the density of granulation. Optimum values between 0.13 and 0.20 have been suggested in order to achieve the highest density in studies [5]. However, the compressive strength of more than 150 MPa has been achieved by injection molding with a ratio of 0.25. Therefore, it can be said that the ratio of water to binders is not the only factor affecting the strength of high strength concrete. Processing process, mixture properties, mixing process are factors affecting the strength of super strong concrete. The decrease in the efficiency of super-strength concrete due to the low ratio of water to adhesive materials can be compensated by adding super-lubricant. The amount of superlubricant consumption depends on the compatibility between the mixed particles and the type of superlubricant. For example, for the same amount of super-lubricant consumption, super-strength concrete containing limestone powder filler is more effective than the mixture containing methaqualene with a higher specific surface area. [6] High-strength concretes are very brittle and brittle due to their high strength and uniformity, which, of course, can be increased by adding steel fibers to the formability of these concretes. [7] The most common fibers used in this field are fibers with a length of 13 mm and a diameter of 0.2 mm. Richard and Chirzi [4] introduced the use of up to 2% of the mixture volume as the appropriate amount of fibers in terms of economy and efficiency in high-strength concrete. Some researchers have also reported that the compressive strength can be reduced by adding fibers. [8] Because adding fibers more than one limit increases the porosity and creates fiber clumps. In the effect of fibers on flexural strength, it can be concluded that when the concrete matrix cracks, the tensile stress is mainly borne by the fibers. When the stress applied to the fibers exceeds the adhesive strength between the fibers and the pulp, separation begins [9]. If the applied stress exceeds the flexural strength of the fibers, the fibers will separate and the cracks will spread and failure will occur. For this reason, the final strength of the mixtures strongly depends on the flexural strength of the fibers at the crack surface. [10]
High-strength fiber concrete is a combination of high-strength concrete and fibers. In other words, it is concrete reinforced by fibers, and its homogeneity has been improved by replacing coarse aggregate with fine aggregate. The compressive strength of super-strength concrete depends on the processing method (standard, thermal and autoclave) and the way it is made. The strength of super-strength concrete can reach 800 MPa [4].
In high-strength concrete, more cement is used than concrete with normal strength or high-strength concrete. With the increase of cement in high-strength concrete, the compressive strength increases. Of course, for values greater than the optimal limit (approximately 1700 kg/m3), the compressive strength will decrease due to the limited involvement of grains. Special cements with a smaller size than ordinary sharp Portland cement have been used in the construction of high-strength concretes [11]. Due to the low ratio of water to binder in high strength concrete, only a part of the whole cement participates in the hydrason process and it is possible to replace unhydrated cement with corroded quartz, silica fume and slag. For example, up to 30, 36, and 40 percent of the cement volume in high-strength concrete can be replaced with corroded quartz, slag, and silica fume, respectively, without having a negative effect on compressive strength [12]. In addition, the addition of silica fume can increase the durability of concrete by filling the space between the aggregates due to its smaller size and shape. In addition, the effect of

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silica fume fine filling through the pozzolanic process can also improve the resistance [4]. Several studies have suggested the consumption of silica fume between 20 and 30% of the total binder volume in order to achieve denser granulation and pozzolanic process and, as a result, more resistance in high-strength concrete. For example, 25% replacement of low carbon cement with silica fume has been introduced as the optimal amount. [13 and 14]. The reason for the decrease in flow due to the addition of fibers can be due to the increase in the specific surface due to the increase in the amount of fibers [15]. Also, steel fibers cause more adhesion between the components of the mixture and prevent the flow of fresh concrete [16]. The shape of the fibers also affects the fluidity. Samples containing crocheted fibers have the lowest fluidity compared to other mixtures. Grunwald [17] observed in his research on high-strength fiber concretes that with the increase in the amount of fibers, the amount of air in the concrete also increased. The reason for that is the influence of fibers on the granularity of concrete components. Due to the internal force between fibers and aggregates, the granulation density decreases.
The porosity also has a similar trend with the amount of air, which has also increased with the increase in the amount of fibers. Of course, the porosity obtained in super strong mixtures is lower compared to ordinary concrete [18]. According to Tazawa's findings, with the same amount of water, with a higher amount of cement, a greater amount of porosity is formed due to shrinkage, so the slight difference between the porosity of the mixtures is due to the difference in their cement amount.
Studies show that the addition of steel fibers can change the behavior of above-mentioned concretes from brittle and sudden to soft and malleable. Various studies have shown that adding a high amount of fibers will not affect the compressive strength, a high amount of fibers can also reduce the compressive strength [19]. By performing thermal treatment, it is possible to increase the strength of concrete by adding fibers. This depends to a large extent on the type and amount of fibers used. For example, the compressive strength increased by 30% in samples containing 2.5% of steel fibers by performing thermal annealing process [20]. This increase in strength in high-strength concrete is due to the improvement in lateral strains instead of the presence of fibers. In addition, the addition of fibers reduces the volume of air trapped in the concrete, which increases the compressive strength by increasing the density [21]. In general, failure in concrete generally begins with failure at the internal surfaces in the transition zone between cementitious materials and aggregates. Therefore, the removal of coarse aggregates in high-strength concrete will lead to the reduction of this type of failure in the transfer zone. In addition, the removal of coarse aggregates will lead to the reduction of empty space in concrete, which will improve the mechanical properties [22]. Fine aggregates such as quartz play a very important role in reducing the maximum thickness of the cement paste, which is a fundamental issue in the design of mix design for high strength concrete. For quartz with a size of 0.8 mm, the optimal ratio of aggregate to cement is suggested as 1.4 [14].

2. Materials, construction, and classification of samples

In this research, for each mixing design, cubic samples with dimensions of 10 cm were made to test compressive strength. 5 mixing designs with different percentages of airgel were made. The specifications of the consumables and the mixing plan are as follows:

Cement

Type 2 cement produced in Ferozabad Fars cement factory was used to make test mixes. The table of chemical analysis of used cement and its comparison with the national standard of Iran is shown in Table 1.

Table 1. Chemical analysis of used cement

$(MgO)\%$	$(SiO_2)\%$	$(Al_2O_3)\%$	$(Fe_2O_3)\%$	$(C_3A)\%$	$(SO_3)\%$	(L.O.I)%	(I.R)%	(CAO)%
1.4	21.2	4.6	3.8	6	2.45	1	0.5	62

Aggregate

Garnet aggregate was selected. Garnet is a group of minerals and is derived from the word granatum. Their dissolution in acids is difficult and they rarely melt. It corresponds to the surface and is classified as silicate, it also has no magnetic properties, and the origin of its formation is magma, pegmatite, metamorphism, adjacent metamorphism, alluvium. Garnet is available in two different sizes, whose physical characteristics can be seen in Table No. 2.the grading curve illustrated in figure 1.

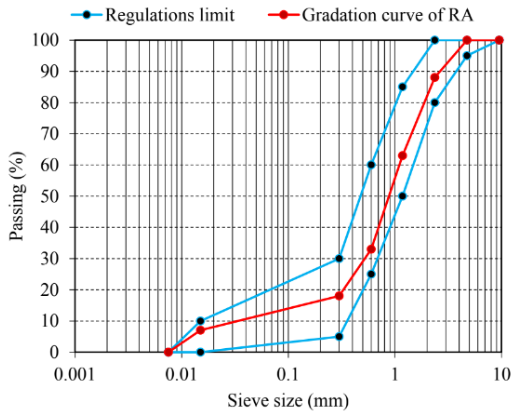


Figure 1. Grading curve for aggregates

Table 2. Physical characteristics of aggregates used

SSD humidity	SSD density	type
0.87	3200	Garnet
1.35	3230	Garnet

Figure 2. Garnet sand used in research

Superplasticizer

To lower the ratio of water to cement base materials, polycarboxylate ether-based superplasticizers have been used. This additive allows the efficient functioning of water in the concrete mixture by dispersing the powder particles, and as a consequence, it enhances the longevity of the concrete in addition to boosting its mechanical qualities. The used superplasticizer is brown in color and manufactured by the Italian Durachem plant. In addition, it has a specific gravity of 1100 kg/m3.

Fiber

The addition of steel fibers to concrete improves its structural qualities, namely its tensile and flexural strength. Several variables, such as the shape, size, volume, percentage, and distribution of fibers, influence the degree to which SFRC outperforms conventional concrete in terms of its mechanical qualities. Utilizing hooked steel fibers in this investigation. The fiber length is 3cm and the flexural strength is 400 Mpa.

3. Making samples and conducting tests

The mixing method included dry mixing of the materials for two minutes, adding water to the mixing mixture in a period of 30 seconds and continuing mixing for 3 minutes. The method of mixing dry materials is also that first, sand is poured into the mixer, and then cement and sewage ash (in designs containing ash) are added to them. At the end, water was poured into the mixer along with the super-lubricant. Immediately after mixing, fresh concrete was poured into the molds. After preparation, the samples were covered with a wet cover for 18 hours to prevent their surface evaporation, then they were placed in a concrete pool containing saturated lime water and kept until the tests. According to the grading chart and also creating the same conditions for all designs, the amount of cement was considered equal to 950 kilograms per cubic meter and the ratio of water to cement was 0.25. 5 mixing plans were made with fiber percentages of 0, 1, 1.5, 2 and 2.5%. The specifications of the mixing design can be seen in Table No. 3.

Table 3. Specifications of mixing design

name	W/c	fiber	cement	garnet	sp
C	0.25	0	950	1600	5.7
S-1	0.25	78.5	950	1475	7.6
S-1.5	0.25	117	950	1458	8.5
S-2	0.25	157	950	1442	9.5
S-2.5	0.25	197	950	1425	9.5

Examining and analyzing the results

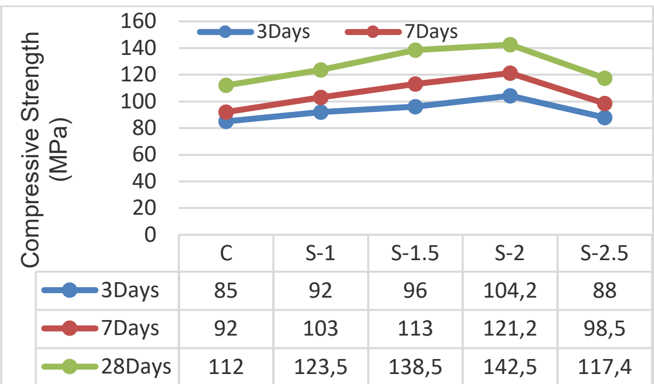
Under normal processing circumstances, the compressive strength of mixes formed at ages 3, 7, and 28 days has been tested. The results of the compressive strength test are shown in Table No. 4.

Table 4. Compressive strength test results (MPa)

Name	3 days	7 days	28 days
C	85	92	112
s-1	92	103	123
s-1.5	96	113	138
s-2	104	121	142
s-2.5	88	98	117

As seen in the table above, the compressive strength of each specimen rises with age. Figure 3 depicts the results of the compressive strength test for ease of review:

Figure 3. Compressive strength



The compressive strength of the design of the mixtures made at the ages of 3, 7 and 28 days has been checked under standard treatments. We will examine them further. Chart No. 1 shows the obtained resistances at the ages of 3, 7 and 28 days for mixtures containing hooked fibers. The results show that by adding steel fibers to the amount of 2 percent by volume of concrete, the compressive strength increases by about 20 to 30 percent at different ages. By increasing the volume of steel fibers up to 2.5%, the compressive strength decreases slightly due to the increase in porosity. But it has more resistance than the sample without fibers. For example, the sample containing 2% fibers has grown by 32, 30 and 25% respectively at the ages of 7, 3 and 28 days compared to the control mixture. The increase in strength in high-strength concrete is due to the improvement in lateral strains due to the presence of fibers. Due to its rigidity, steel fibers are effective in compressive strength and bear load as a part of concrete, and since they are enclosed by the concrete matrix, they do not buckle and cause an increase in strength. Due to the gradual nature of fiber elongation from concrete in the deformation after matrix cracking, fibers play an effective role that the improvement in the deformation of materials depends on the type and volume percentage of fibers. Fibers in wavy shapes and rough surfaces with hooked ends have a great effect in increasing the flexural strength. Such types of fibers are effective compared to simple and straight types, and usually the percentage of volume used in this type of fiber to reach a certain level of resistance and deformation is lower than simple and straight samples. Soroushian et al. By incorporating steel fibers, the qualities of high-strength concrete were explored. The test findings revealed that the flexural strength grows linearly with the number of steel fibers, with the rate of growth being greatest in the first seven days. Cranchel et al. [24] conducted an experiment to examine the behavior of concrete slabs reinforced with steel fibers and polypropylene. The test findings indicate that an increase of 1% in the amount of steel fibers has the greatest impact on the formability of slabs. During his study on high-strength self-compacting concrete, El Dibeh [25] observed that the insertion of steel fibers decreases the flowability, and this loss intensifies as the number of fibers increases. In the same concrete without fibers, a rapid rupture and total disintegration occur. While concrete with steel fibers has a ductile characteristic and ruptures slowly, this is not the case for concrete without steel fibers. Thus, the presence of steel fibers in concrete influences the mechanism of failure. Additionally, the addition of steel fibers to the previously described concrete boosts its compressive and flexural strengths. (El Dibeh 2009)

4. Conclusion

- Adding hooked steel fibers to super-strength concrete decreases the concrete's flowability, but this loss may be compensated for by increasing the quantity of superlubricant.
- The addition of fibers to high-strength concrete has no influence on the process of strength development, and in all circumstances, concrete strength increases with age.
- Adding 2 percent by volume of steel fibers to concrete raises the compressive strength by 20 to 30 percent at various ages.
- Due to the increase in porosity, the compressive strength falls when the amount of steel fibers is increased by up to 2.5%.
- The inclusion of steel fibers has enhanced the porosity and, therefore, the water absorption capacity. Utilizing 1.5 and 2.5% steel fibers improves water absorption by 33 and 60%, respectively.
- Due to the increased porosity of the mixture including fibers, the volume of permeable pores has increased to 22, 16, 9, and 30 percent when 1, 1.5, 2, and 2.5 percent of the volume of concrete is replaced with hooked steel fibers.
- The chloride ion diffusion coefficient rises by 18, 28, 34, and 52 percent when 1, 1.5, 2, and 2.5 percent steel fibers are added to a material.
- There is no correlation between the results of accelerated chloride ion penetration and compressive strength. Likewise, there is no correlation between the durability properties and the mechanical properties of the mixtures. This is because steel fibers have increased the mechanical properties but decreased the durability of the mixtures.

References

[1.] Tang, C. (2004). High performance concrete—past, present and future. In Proceedings of the International Symposium on UHPC, Kassel, Germany (pp. 3–9).

[2.] Schmidt, M., Fehling, E., & Geisenhanslueke, C. (Eds.). (2004). International Symposium on Ultra High Performance Concrete, Kassel, Germany (p. 868).

[3.] R.Yu, P.Spiesz,H.J.H.Brouwers," Development of an eco-friendly Ultra-High Performance Concrete (UHPC) with efficient cement and mineral admixtures uses", Cement and Concrete Composites, Volume 55, January 2015, Pages 383-394.

[4.] Richard, P., & Cheyrezy, M. (1995). Composition of reactive powder concretes. Cement and Concrete Research, 25, 1501–1511.

[5.] Shi, C., Wu, Z., Xiao, J., Wang, D., Huang, Z., & Fang, Z. (2015). A review on ultra-high performance concrete: Part 1. Raw materials and mixture design. Construction and Building Materials, 101, 741–751.

[6.] Rougeau, P., & Burys, B. (2004). Ultra-high performance concrete with ultrafine particles other than silica fume. In Proceedings of the International Symposium on UHPC, Kassel (pp. 313–325).

[7.] Wang, D., Shi, C., Wu, Z., Xiao, J., Huang, Z., & Fang, Z. (2015). A review on ultra-high performance concrete: Part I. Hydration, microstructure and properties. Construction and Building Materials, 96, 368–377.

[8.] N. Banthia, R. Gupta, Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices, Mater. Struct. 37 (10) (2004) 707–716.

[9.] A.E. Naaman, G.G. Namur, J.M. Alwan, H.S. Najm, Fiber pullout and bond slip. I: Analytical study, J. Struct. Eng. 117 (9) (1991) 2769–2790.

[10.] M. Xu, B. Hallinan, K. Wille, Effect of loading rates on pullout behavior of high strength steel fibers embedded in ultra-high performance concrete, Cem Concr Compos 70 (2016) 98–109.

[11.] Talebinejad, I., Iranmanesh, A., Bassam, S., & Shekarchizadeh, M. (2004). Optimizing mix proportions of normal weight reactive powder concrete with strengths of 200–350 MPa.

[12.] Strunge, T., & Deuse, T. (2008). Special cements for ultra-high performance concrete. In Proceedings of the Second International Symposium on Ultra High Performance Concrete, Kassel, Germany (pp. 61–68).

[13.] Xing, F., Huang, D., Cao, L., & Deng, L. (2006). Study on preparation technique for low-cost green reactive powder concrete. Key Engineering Materials, 302–303, 405–410.

[14.] Wille, K., Naaman, A., & Montesinos, G. (2011). Ultra-high performance concrete with compressive strength exceeding 150 MPa (22 ksi): a simpler way. ACI Materials Journal, 108(1), 46–54.

[15.] R. Yu, P. Spiesz, H.J.H. Brouwers, Mix design and properties assessment of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC), Cement and Concrete Research 56 (2014) 29–39.

[16.] X.M. Gao, Effect of Steel Fiber on the Performance of Ultra-High Performance Concrete, Hunan University, Changsha, 2013 (in Chinese, dissertation).

[17.] S. Grünewald, Performance-based design of self-compacting fibre reinforced concrete, Delft University of Technology, Delft, the Netherlands, 2004.

[18.] M.d Safiuddin, N. Hearn, Comparison of ASTM saturation techniques for measuring the permeable porosity of concrete, Cem. Concr. Res. 35 (2005) 1008–1013.

[19.] A.S. EL-Dibe, Mechanical, durability and microstructural characteristics of ultra-high strength self-compacting concrete incorporating steel fiber, Materials and Design, 30,4286-4292, (2009).

[20.] Graybeal, B. (2007). Compressive behaviour of ultra-high-performance fibre-reinforced concrete. ACI Materials Journal, 104(2), 146–152.

[21.] Abbas, S., Soliman, A., & Nehdi, M. (2015). Exploring mechanical and durability properties of ultra-high performance concrete incorporating various steel fiber lengths and dosages. Construction and Building Materials, 75, 429–441.

[22.] Mehta, K., & Monteiro, J. (2006). Concrete: Microstructure, properties, and materials (4th ed., p. 659). New York, NY: McGraw-Hill.

[23.] Soroushian, P. and Lee, C, "Flexural strength of steel fiber reinforced concrete: correlation with some measures of fiber spacing." ACI Material Journal, Vol. 87, No. 6, PP. 541-546, (1990).

[24.] Krenechel, h," Fiber reinforcement", Akademisk Forlag, Copenhagen, PP. 158, (1964).

[25.] El-Dieb, A. (2009). Mechanical, durability and microstructural characteristics of ultrahigh-strength self-compacting concrete incorporating steel fibers. Materials and Design, 30, 4286–4292.

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