

Abbreviations

Co	Reference Concrete
HPC	High Performance Concrete
HPC _{0.5}	High Performance Concrete with 0.5% Steel Fiber by Volume
HPC _{1.0}	High Performance Concrete with 1.0% Steel Fiber by Volume
HPC _{1.5}	High Performance Concrete with 1.5% Steel Fiber by Volume

INTRODUCTION

Steel fibrous reinforced concrete is important as it plays a part in developing of modern concrete technology, hence it represents a new construction concrete. Recently, extensive research efforts have been exerted to investigate the possibility of using steel fibers and chemical and mineral admixtures in producing high strength steel fiber reinforced concrete. However, in spite of the intensive demand and vital importance of high performance steel fiber reinforced concrete in special application, very limited amount of published literatures were available.

Paillere et al. [1] investigated the effect of fiber addition on the autogenously cracking of silica fume concrete. The tests showed that steel fibers can lengthen the time elapsed before cracking and can provide a confinement after cracking of silica fume concrete. As in the case of conventional concrete, the use of steel fibers substantially increases the energy of high-strength concrete. The tests also show that the resulting concrete can be kept reasonably workable by modifying the sand/aggregate ratio in the composition of the concrete and using fibers having a relatively low aspect ratio.

Zhang and Malhotra [2] presented results on the physical and chemical properties of rice husk ash (RHA), with the properties of fresh and hardened concrete incorporating the same ash. In addition to the effects of the percentage of RHA and the water-cementitious materials ratio on the properties investigated, the properties of RHA concrete were also compared with those of the control Portland cement concrete and silica fume concrete. The test results indicate that the RHA is highly active Pozzolan and can be used as a supplementary cementing material to produce high-performance concrete.

Al-Sakiny [3] investigate the effect of steel fibers content, high range water reducing agent (HRWRA) and the combined effect of rice husk ash (RHA) and (HRWRA) in producing ultra high strength fiber reinforced concrete. The results demonstrated that reference concrete reinforced with 2%, 2.5% and 3% steel fibers by volume showed a slight-reduction in compressive strength at early ages of curing. On the other hand, this concrete showed a significant increase in other properties.

The results also demonstrated that the incorporation of HRWRA in concrete led to a considerable improvement in compressive, splitting tensile and flexural strength, static modulus of elasticity, Poisson's ratio and impact resistance. Where the inclusion of 8% RHA, as a partial replacement by weight of cement, with HRWRA showed superior performance in these properties over those of HRWRA concrete.

Ameir [4] investigated the engineering properties of high performance lightweight aggregate concrete containing various types of chemical, mineral admixtures and steel fibers. Results indicate that, HRWRA fiber reinforced lightweight aggregate concrete showed considerable improvement in compressive, splitting, flexural strengths, impact resistance, static modulus of elasticity and Poisson's ratio at 60 and 90 days of curing compared to fiber reinforced lightweight aggregate concrete without HRWRA. On the other hand, the inclusion of 8% RHA as partial replacement by weight of cement with optimum dosage of HRWRA showed superior performance over those of HRWRA fiber reinforced concrete.

EXPERIMENTAL WORK

Materials

Cement

The cement used throughout this work was Ordinary Portland Cement produced by Kubaysa Cement Factory. It is stored in airtight plastic containers to avoid exposure to different atmospheric conditions. The chemical analysis and physical test results of the used cement are given in Tables (1) and (2) respectively. It conforms to the Iraqi specification No. 5/1984 [5].

Table (1): Chemical Analysis of Cement

Compound composition	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	L.O.I	L.S.F.	I.R.
Percentage by weight	61.8	22.2	4.4	2.76	2.7	2.5	1.9	0.87	1.5
Limits of Iraqi spec. No. 5/1984	-	-	-	-	≤2.8 %	≤5.0 %	≤4.0 %	0.66-1.02 %	≤ 1.5 %

Fine aggregate

Al-Ukhaider natural sand of 4.75-mm maximum size was used for concrete mixes of this investigation. The sieve analysis of the used sand is shown

in Table (3). It conforms to the limits of Iraqi specification No. 4/1984, Zone (3). The specific gravity, absorption, sulfate content and material finer than sieve No. 200 (75 μm) of the used fine aggregate were (2.62, 1.19%, 0.2% and 0.8%) respectively. These tests were performed according to ASTM C 128-88 [6].

Table (2): Physical Properties of Cement*

Physical properties	Test result	Limits of Iraqi spec. No. 5/1984
Specific surface area Blaine method, m^2/kg	379	$\geq 230 \text{ m}^2/\text{kg}$
Setting time, Vicat's method:		
Initial setting, hrs: min.	3:17	≥ 1 hour
Final setting, hrs: min.	4:45	≤ 10 hour
Soundness (%)	0.2	≤ 0.8
Compressive strength of mortar, N/mm^2 :		
3 days	15.8	$\geq 15 \text{ N}/\text{mm}^2$
7 days	27.5	$\geq 23 \text{ N}/\text{mm}^2$

* Chemical and physical tests were made by the National center for construction laboratories.

Coarse aggregate

The washed coarse aggregate used was crushed aggregate of 10-mm maximum size. It brought from Al-Nibaey region. The sieve analysis of this aggregate is shown in Table (3). It conforms to the Iraqi specification No. 45/1984. The specific gravity, absorption, sulfate content and material finer than No. 200(75 μm) sieve of the used coarse aggregate were (2.68, 1.07%, 0.07%, and 0.2%) respectively. These tests were performed according to ASTM C 127-88 [7].

Table (3): Grading of Fine and Coarse Aggregates

Sieve size (mm)		Accumulated percentage passing (%)		Limit of Iraqi specification No. 45/1984	
Fine Aggre-	Coarse Aggre-	Fine Aggre-	Coarse Aggre-	Fine Aggre- , Zone (3)	Coarse Aggre-
4.75	12.5	100	100	90-100	100
2.36	9.5	95	99	85-100	85-100
1.18	4.75	90	15	75-100	10-30
0.60	2.36	75	3	60-79	0-10
0.30	1.18	38	0	12-40	0-5
0.015	-	7.5	-	0-10	-

Mixing water

Ordinary potable water was used for mixing and curing purposes.

Steel fibers

High tensile steel fibers crimped type was used with different volume fractions of (0, 0.5, 1 and 1.5%). Table (4) shows the properties of the used steel fibers.

Table (4): Properties of Steel Fibers (Crimped Type)

Property	Specifications
Density	7860 kg/m ³
Ultimate strength	1500 Mpa
Modulus of elasticity	2 *10 ⁵ Mpa
Poisson's ratio	0.28
Length	50 mm
Diameter	0.5 mm
Aspect ratio	100

High-range water-reducing admixtures (Superplasticizer) type Melment L10

The melamine formaldehyde condensate Type (F) according to ASTM C494-86 [8] was used as superplasticizer for some concrete mixes. It is commercially known as Melment L10. It was produced by Baghdad Company for building chemicals. In this study a 28.2% water reduction was obtained by adding 6% Melment L10 by weight of cement.

Polyvinyl dispersion (BVD)

Due to the requirement of the manufacturer, another type of superplasticizer was used to extend the initial setting time for the mix, without any losses in the reduced water/cement ratio. This type of admixture called polyvinyl dispersion (BVD) type supplied by Al-Zahaf Al-Kabir Company. The dosage recommended by the company is about (0.4%) by weight of cement. This type of admixture meets the requirements of the ASTM C 494-86 type B and D [8].

Rice husk ash (RHA)

Rice husks are the shells produced by dehusking process of paddy rice. In this investigation burning of rice husks was carried out in a furnace with controlled temperature in order to establish the optimum burning temperature and burning time. It was found that the combustion temperature of about 550 °C and duration time of 2 hrs produced on ash with optimum properties.

The physical properties and the chemical composition of RHA are shown in Tables (5) and (6) respectively. The chemical analysis indicates that the RHA consists of 84.52% SiO₂ and the loss on ignition was low (4.32%). The RHA used in this work conform to the chemical and physical requirements of ASTM (618), class N pozzolan [9].

Table (5): Physical Properties of Rice Husk Ash (RHA)*

No.	Property	Result
1	Fineness	18650 cm ² /gm
2	Specific gravity	2.03

* Physical tests were made by the National center for construction laboratories.

Table (6): Chemical Analysis of RHA*

Content	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	L.O.I
Percentage	84.52	0.72	2.95	1.3	0.83	0.07	2.15	1.93	4.32

* Chemical tests were made by the National center for construction laboratories.

The Experimental Program

The experimental program was planned to investigate the effect of using steel fiber with high performance concrete on the mechanical properties of concrete. Table (7) shows the details of reference and high performance concrete with and without steel fiber mixes used throughout this work.

Preparation of concrete specimens

The concrete mix was designed according to the 1986, British Standard Method. The reference concrete mix designed to have a 28 days, compressive strength of about (50) MPa and slump 100 ± 5 mm. The maximum size of the used aggregate was (10 mm). According to the mix design procedure, concrete mix with a weight proportions of (1:1.15:1.73) and water/cement ratio of (0.41) was used as a reference concrete.

Table (7): Details of the Experimental Program, Mix Proportions, 1:1.15:1.73 (by weight), with Slump 100 mm

Mix designation	Cement content Kg/m ³	(W/C) or (W/Cm)* to give slump 100 ± 5 (mm)	Water reduction (%)	Steel fiber content by volume (%)
C ₀	550	0.41	0	0
HPC	506	0.294	28.2	0
HPC _{0.5}	506	0.303	26.1	0.5
HPC _{1.0}	506	0.311	24	1
HPC _{1.5}	506	0.32	21.9	1.5

* W/Cm ratio: Water/ cemented materials ratio

Mixing procedure

A mechanical mixer of (0.1) m³ capacity was used to mix concrete to obtain the required workability and homogeneity. The interior surface of the mixer cleaned and moistened before placing the materials.

For reference concrete the dry constituents, were placed in the mixer such that cement is placed between two layers of gravel and sand. The dry materials were well mixed for about 1.5 minutes to attain uniform mix. The required quantity of tap water was then added and the whole constituents were mixed for other two minutes.

To mixing the raw material for high performance concrete the above procedure was used expect that the 8% RHA [1,4,10] be mixed with the quantity of cement by the aid of trowels. The water content of admixture (HRWRA and BVD) was deducted from the desired w/c ratio. The HRWRA and BVD were added to the mixing after added the mixing water by 3 minutes and the mixing was continued to attain uniform mix.

For mixing high performance steel fiber reinforced concrete, first the coarse and fine aggregate were mixed with 1/3 of the mixing water for 1 minute. Then cement with RHA and remaining water were added, and the ingredients mixed for 3 minutes. After that, the admixtures and fibers were added, and the mixing was contained for suitable time (until the concrete becomes homogenous in consistency).

Casting compaction and curing

The molds were lightly coated with mineral oil before use, according to ASTM C 192-88 [11], concrete casting was carried out in different layer each layer of 50 mm. Each layer was compacted by using a Vibrating Table for (15-30) second until no air bubbles emerged from the surface of the concrete, and the concrete is leveled off smoothly to the top of the molds. Then the specimens were kept covered with polyethylene sheet in the laboratory for about (24 ± 2) hrs. After that the specimens remolded carefully, marker and immersed in water until the age of test. The age of tests were 7, 28 and 90 days for control tests.

Testing of Hardened Concrete

Compressive strength test

Based on BS 1881: part 5 [12], the compressive strength was carried out on 100x100x100 mm cube specimens. The compressive strength was taken as the average value of three specimens.

Splitting tensile strength test

The splitting tensile strength was conducted on cylinders of (100 * 200 mm). The average of three test specimens was taken. The test was carried out in accordance with ASTM C 496-86 [13].

Flexural strength test

This test was done according to ASTM C 78-84 [14]. The flexural strength was carried on 100x100x500-mm prism. The flexural strength was taken as the average value of three specimens.

RESULTS AND DISCUSSIONS

Compressive strength

The compressive strength development at various curing ages for all types of concrete are presented in Table (8) and Figure (1). Results demonstrated that in general, all concrete specimens exhibited continuous increase in compressive strength with increase of curing age.

Table (8): Average Compressive Strength Results

Mix designation	(W/C) or (W/Cm) to give slump 100 ± 5 (mm)	Water reduction (%)	Compressive strength (MPa) at		
			7 days	28 days	90 days
C ₀	0.41	0	34.5	52	54
HPC	0.29	28.2	56	60.5	62.5
HPC _{0.5}	0.30	26.1	56.5	63	72.25
HPC _{1.0}	0.31	24	56.5	67.5	76
HPC _{1.5}	0.32	21.9	56	62.5	73

After 7 days curing the compressive strength of concrete was increased with different percentage. The percentage increase of HPC was 62.3% relative to reference concrete, this increasing was attributed to action of high range water reducer. This behavior was mainly ascribed to the significant reduction in water content of the concrete caused by inclusion of this type of chemical admixture. The other advantage that attained by incorporation high range water reducing admixture in concrete is the dispersion of cement agglomerates into individual particles and deflocculating the watery enttringite shell around the cement particles providing a more uniform and consistent structure of concrete.

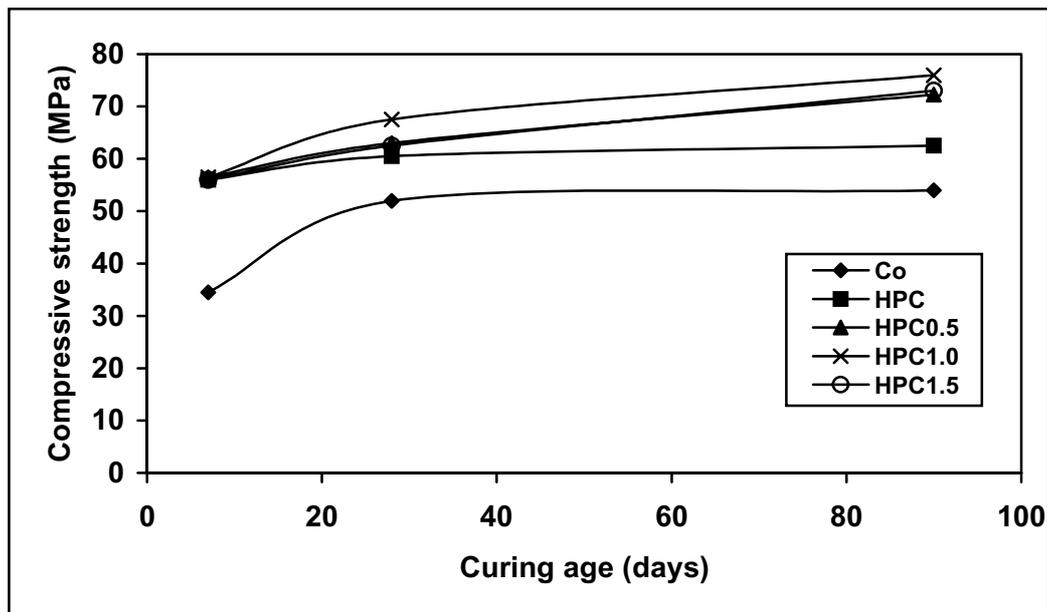


Figure (1): Compressive Strength of Various Type of Concrete Cured at Different Ages

The addition of steel fiber to HPC (up to volume fraction of 1.5%) caused an increase in compressive strength of concrete at early ages. At 7 days curing the increasing percentage were 63.7%, 63.7% and 62.3% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively, Figure (2).

From Table (8) and Figure (2), it can be seen that the addition of 1.5% steel fiber did not cause any increase in compressive strength at 7 days. This attributed to the increase of air voids in concrete due to an increase in water-cement ratio, which is required to maintain a given workability, where the compressive strength is very sensitive to the presence of these voids. After 28 days curing the percentage of increase in compressive strength of HPC relative to reference concrete was 16%, while the increase for high performance concrete with steel fiber (HPSFC) were 12.1%, 29.8% and 20.19% for 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively, Figures (1) and (2).

From Table (8) and Figures (2) and (3), after 28 days curing the effect of increase due to steel fiber will be more active, which is attributed to the concentration of the product of hydration process around the steel fiber and in voids of concrete.

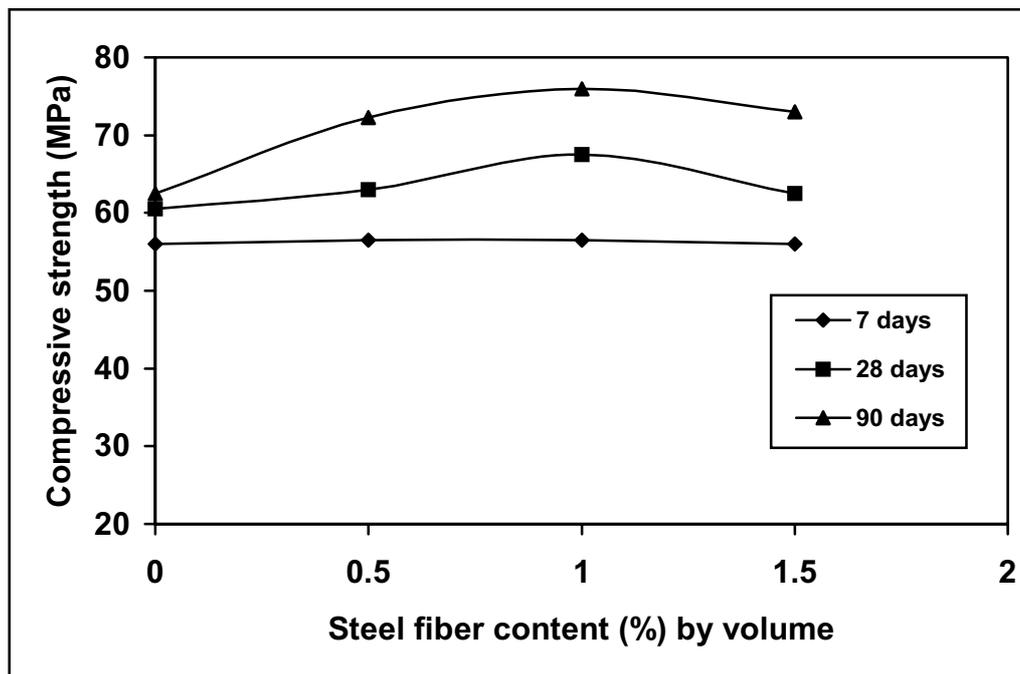


Figure (2): Effect of Steel Fibers on Compressive Strength at Different Curing Ages

Results at 90 days indicated that the compressive strength for all types of concrete increases in different percentages with the increase of steel fiber content. The increase in compressive strength compared to reference concrete were 15.7%, 33.79%, 40.7 and 35.1% for HPC and HPC with 0.5%, 1% and 1.5% steel fibers content by volume of concrete, respectively.

From Table (8) and Figures (2) and (3) it can be seen that the increase in compressive strength of high performance steel fiber concrete at 90 days was greater than their corresponding compressive strength at 28 days. Such increase in compressive strength was attributed to the intensive product of hydration process around the steel fiber and mainly associated with the pozzolanic reaction of rice husk ash (RHA).

In general the increase in compressive strength of high performance steel fiber concrete is attributed to the capability of steel fiber to delay the unstable development of microcracks. As well as limitation the propagation of these microcracks and the composite effect for concrete and steel fibers under load i.e. (associated the steel fiber in strength of external loads). However there may be merit in including fibers to provide increased ductility in a compressive failure.

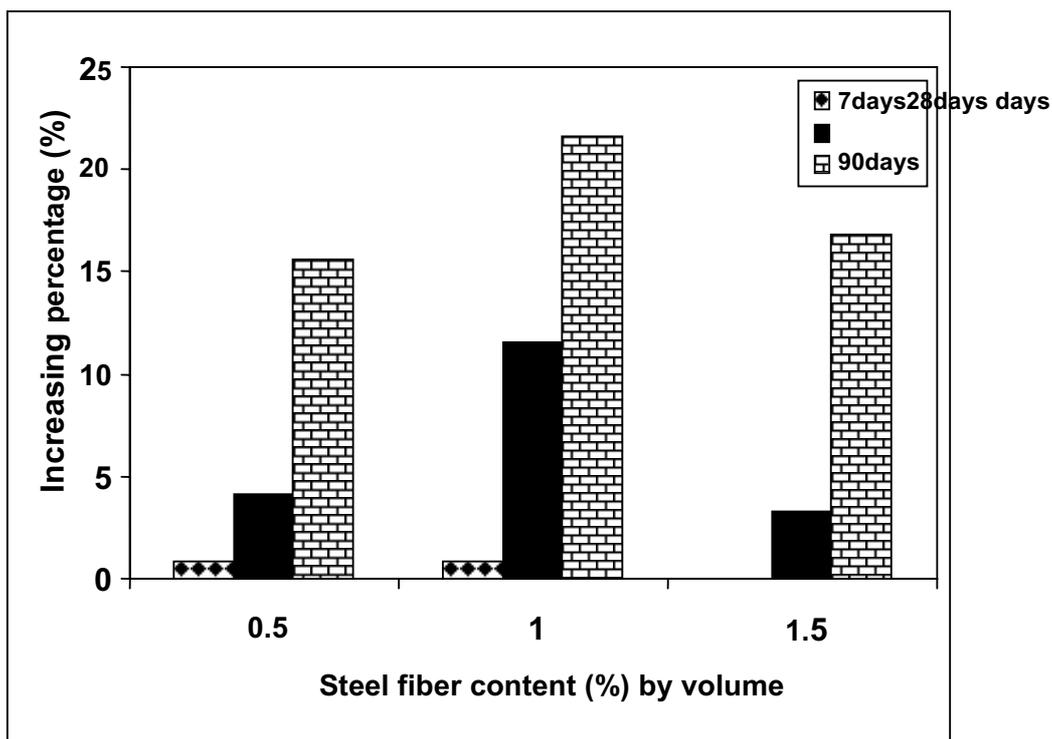


Figure (3): Relationship between the Steel Fiber Content and Increasing Percentage in Compressive Strength at Different Ages

Splitting tensile strength

The splitting tensile strength was determined at ages of (7, 28 and 90 days) for moist cured concrete specimens. The test results of the splitting tensile strength are reported in Table (9) and plotted in Figure (4). The results indicated that in general, all types of concrete specimens exhibited continued increase in splitting strength with development of curing ages.

From Table (9) and Figure (4), it is observed that the splitting tensile strength of HPC increase at all ages of curing compared with the reference concrete. This increase may be ascribed to the significant reduction in capillary porosity of the cement matrix, as well as to good dispersion of the cement grains throughout the mix, thereby increasing bond strength leading to a significant increase in splitting tensile strength. The percentage of increases in splitting tensile strength relative to reference concrete were 66.66%, 39.18% and 26.9% at 7, 28, 90 days, respectively.

Table (9): Average Splitting Tensile Strength Results

Mix designation	(W/C) or (W/Cm) to give slump 100 ± 5 (mm)	Water reduction (%)	Splitting tensile strength (MPa) at		
			7 days	28 days	90 days
Co	0.41	0	2.1	3.42	3.9
HPC	0.29	28.2	3.5	4.76	4.95
HPC _{0.5}	0.30	26.1	4.43	5.7	6.15
HPC _{1.0}	0.31	24	5.25	6.52	6.93
HPC _{1.5}	0.32	21.9	5.75	7.6	8.25

The HPC with steel fiber showed a significant increase in splitting tensile strength with increase in steel fiber content at all ages of curing compared with reference and high performance concrete, Figs. (4) and (5). This behavior is attributed to the mechanism of steel fibers in arresting crack progression, where the increase in fibers content leads to increase in crack arrestors point, thereby, increasing the tensile strength.

The percentages of increase in splitting tensile strength of high performance steel fiber concrete (HPSFC) relative to reference concrete at 7 days were 110.9%, 150% and 173.8% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively. The percentage of increase in splitting tensile strength of HPSFC relative to HPC were 26.5%, 50% and 64.28% for HPC with

0.5%, 1% and 1.5% steel fiber content by volume of concrete respectively, Figure (6).

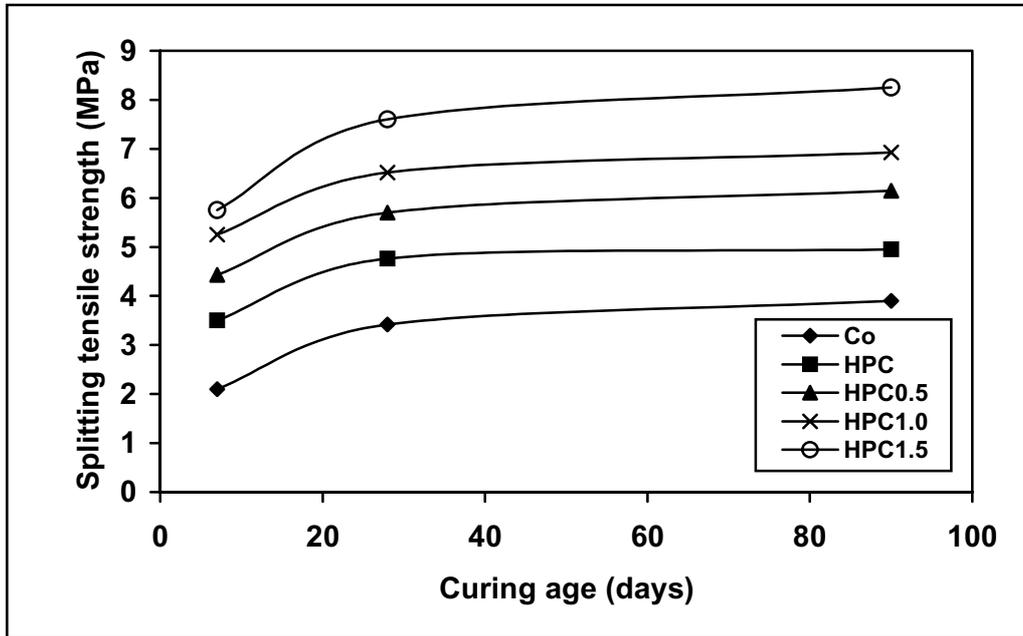


Figure (4): Splitting Tensile Strength of Various Type of Concrete Cured at Different Ages

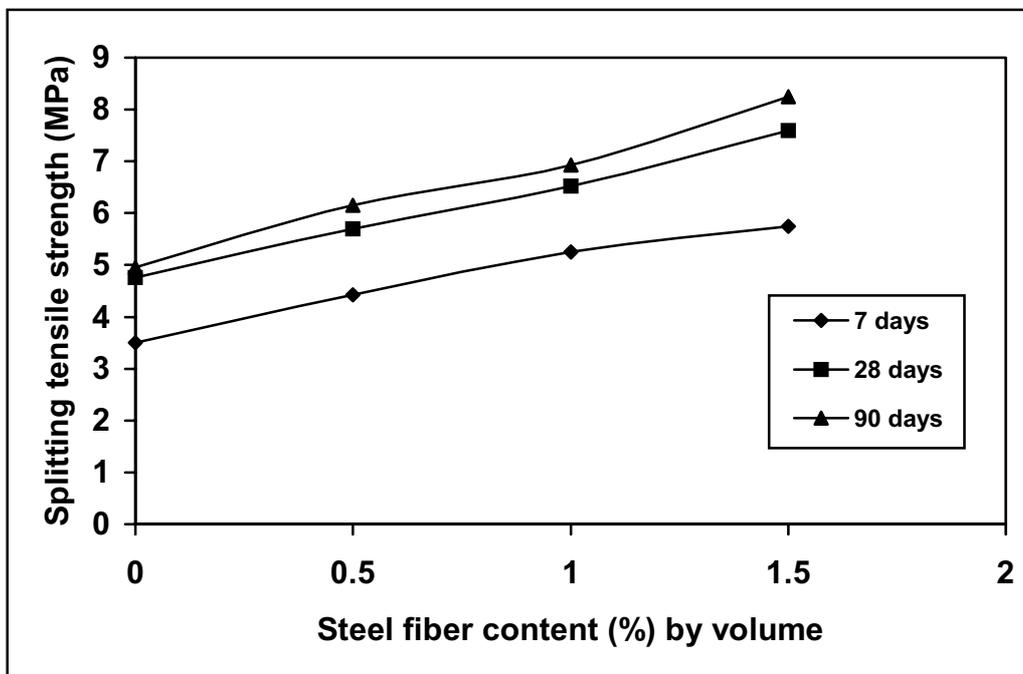


Figure (5): Effect of Steel Fiber on Splitting Tensile Strength at Different Curing Ages

After 28 days curing, the percentage increase in splitting tensile strength of HPSFC relative to reference concrete were 66.66%, 90.6% and 122.22% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively, Figure (5). The percentage increase in splitting tensile strength for HPSFC relative to HPC were 19.7%, 36.9% and 63.8% for HPC with 0.5%, 1%, 1.5% steel fiber by volume of concrete, Figure (6).

The splitting tensile strength exhibited a significant increase after a curing age of 90 days. This increase is attributed to the development of hydration and mainly associated with the pozzolanic reaction of the RHA with calcium hydroxide, which was liberated during the hydration of cement. It contributed to the densification of concrete matrix, thereby strengthening the transition zone and reducing the microcracking leading to significant increase in tensile strength.

At 90 days of curing the HPSFC exhibited a percentage increase relative to the reference concrete of 57.69%, 77.69% and 111.53% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively, and the increase relative to HPC were 24.24%, 40% and 66.66% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete, Figures (5) and (6).

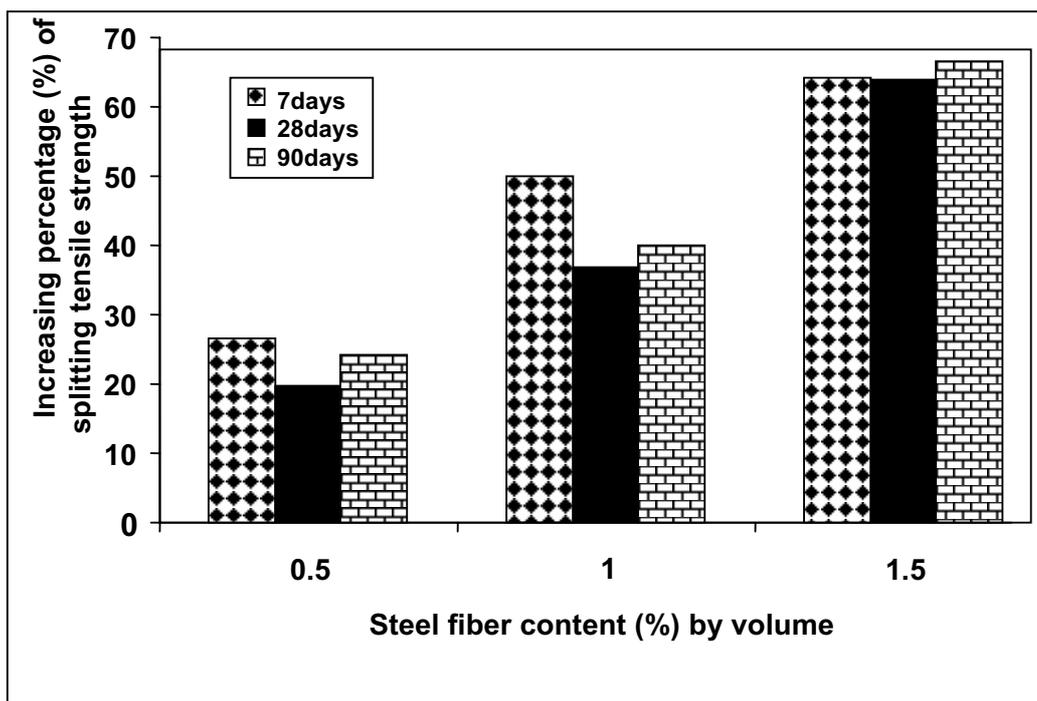


Figure (6): Relationship between the Steel Fiber Content and Increasing Percentage in Splitting Tensile Strength

Flexural strength

The flexural strength was determined at ages (7, 28 and 90 days) for moist cured concrete prisms of (100×100× 400) mm dimensions. The results are given in Table (10). The effect of curing ages on the flexural strength on various types of concrete was presented in Figure (7). The results indicated that with the progress of curing ages all concrete specimens showed a continuous gain in flexural strength. HPC performed considerably better than the corresponding reference concrete, Figure (7). This is attributed to the reduced capillary porosity caused by the reduction of the water content of the mix, in addition to defloculation or dispersion of the cement agglomerates into primary particles. Further, the dispersion system will include particles spaced at a more uniform distance from one another. Thereby on continuing hydration there is a greater statistical chance of intermeshing of hydration product with fine and coarse aggregates surface to produce a system of higher internal. The percentage increase in flexural strength of HPC compared with reference concrete were 15.69%, 22.14% and 11.62% for 7, 28 and 90 days, respectively.

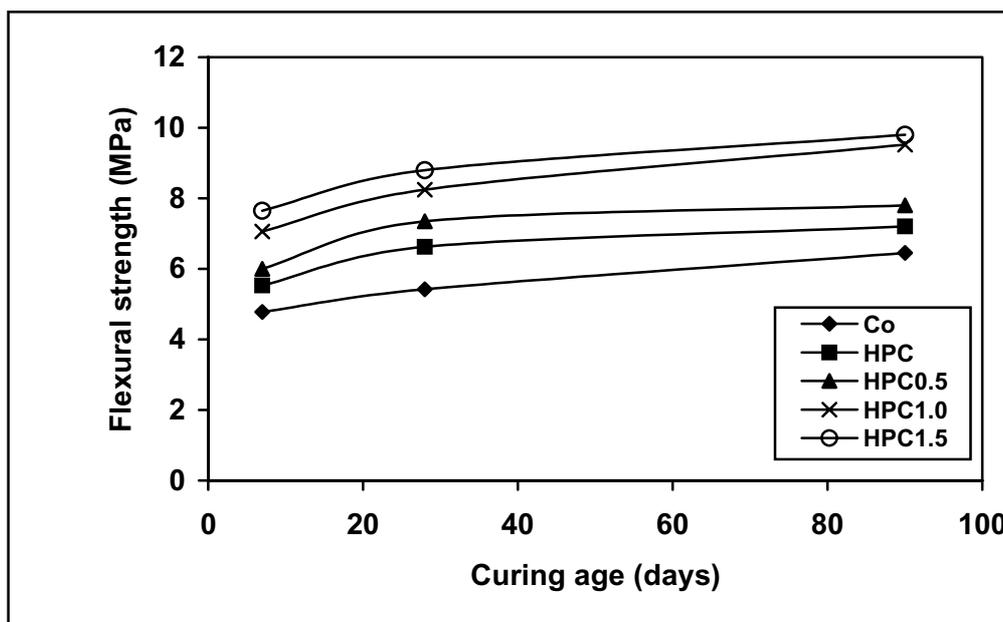


Figure (7): Flexural Strength of Various Type of Concrete Cured at Different Ages

High Performance steel fiber concrete exhibited increasing flexural strength with increasing in steel fibers compared with reference and HPC. This behavior is mainly attributed to the role of steel fiber in releasing fracture energy around crack tips which is required to extent crack growing by transferring stress from one side to another side. Also this behavior is due to the increase in crack resistance of the composite and the ability of fibers to resist forces after the concrete matrix has cracked.

Table (10): Average Flexural Strength Results

Mix designation	(W/C) or (W/Cm) to give slump 100 ± 5 (mm)	Water reduction (%)	Flexural strength (MPa) at		
			7 days	28 days	90 days
Co	0.41	0	4.78	5.42	6.45
HPC	0.29	28.2	5.53	6.62	7.20
HPC _{0.5}	0.30	26.1	6.00	7.35	7.80
HPC _{1.0}	0.31	4	7.06	8.24	9.52
HPC _{1.5}	0.32	21.9	7.65	8.80	9.80

The percentage increase in flexural strength relative to reference concrete at 7 days were 25.52%, 47.69%, and 60.04% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively. The percentage increase relative to HPC at 7 days were 8.4%, 27.6% and 38.3% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively Figs. (8) and (9).

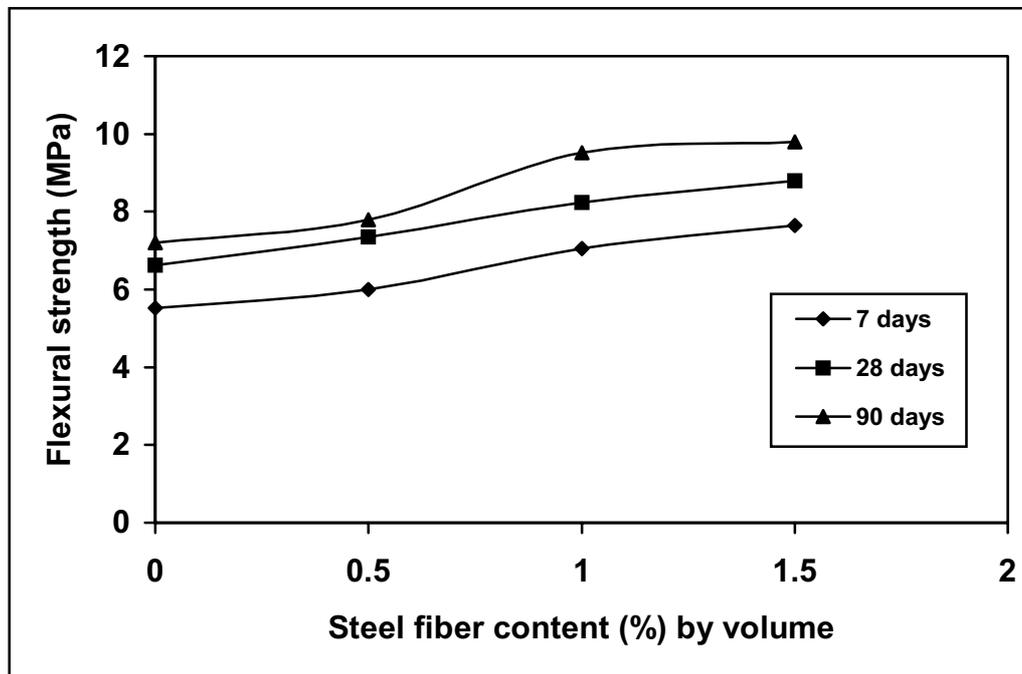


Figure (8): Effect of Steel Fiber Content on Flexural Strength of Concrete at Different Ages

After 28 days curing the increases in flexural strength of HPSFC relative to reference concrete were 35.6%, 52.02%, and 62.36% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively Fig (7). The increasing in flexural strength for HPSFC relative to HPC were 11.02%, 24.47%, and 32.9% for HPC with 0.5%, 1%, and 1.5% steel fiber by volume of concrete respectively, Figures (8) and (9).

The flexural strength exhibit increase at 90 days curing. This behavior may be ascribed to pore and grain size refinement processes strengthen the transition zone and reduces the microcracking in the interface, this caused by pazzolanic reaction.

The increase in flexural strength for HPC with steel fiber relative to reference concrete were 20.93%, 47.59% and 51.93% for HP with 0.5%, 1%, and 1.5% steel fiber by volume of concrete. The increasing relative to HPC were 8.33%, 32.22% and 36.11% for HPC with 0.5%, 1%, and 1.5% steel fiber by volume of concrete Figs. (8) and (9).

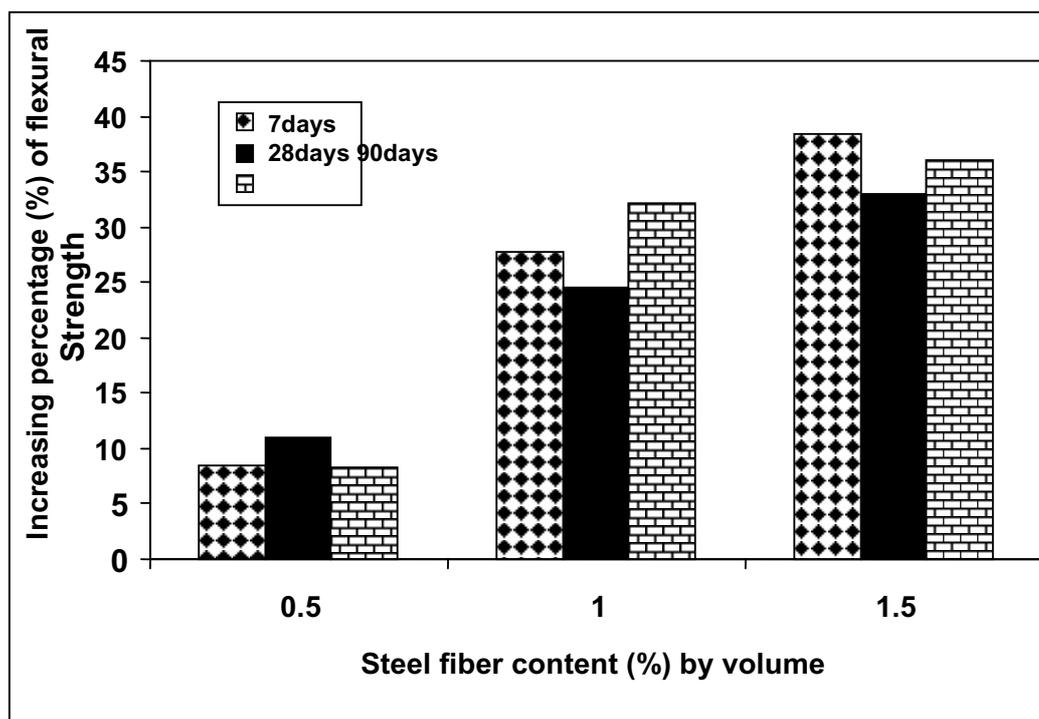


Figure (9): Relationship between the Fiber Content and Increasing Percentage in Flexural Strength of Concrete

CONCLUSIONS

Depending on the results of this investigation, the following conclusions can be drawn: -

1. At optimum dosage of superplasticizer 6% by weight of cement, the maximum water reductions were 28.2% for HPC and 26.2%, 24% and 21.9% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete, respectively.
2. The addition of steel fibers (0.5% and 1%) to HPC leads to increase the compressive strength of HPC, but it decreased at 1.5% steel fiber. The optimum volume fraction of steel fiber was 1%, 8% RHA and 6% superplasticizer were used to improve the compressive strength of concrete, the percentage increases were 0.89%, 11.57% and 21.6% at 7, 28, and 90 days, respectively.
3. The splitting tensile strength increases with age and with the increase of steel fiber contents. HPC with 1.5% steel fiber exhibited superior increase in splitting tensile strength. The percentage increases relative to HPC were 64.28%, 63.86% and 66.66% at 7, 28 and 90 days, respectively.
4. The flexural strength, of HPC concrete increases with the increase of steel fiber contents up to 1.5%. The percentage increases relative to HPC were 38.33, 32.93 and 36.11 at 7, 28 and 90 days, respectively.

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