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Araştırma Makalesi / Research Article

Assessment of High-Performance Fiber Reinforced Concrete (HPFRC) Durability Due to Exposing to Different Environmental Media

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Abstract

The durability and mechanical properties of HPFRC are experimentally investigated in this study after being exposed to four different media. Those media were air, water, sodium chloride, and magnesium sulfate with 7% concentration for both chloride and sulfate. Hooked-end galvanized steel fiber 50 mm length with three different fiber volume fractions, Vf, as follows 0.5%, 1.0% and 1.5% and polypropylene fiber with, Vf, 0.1%, 0.3%, and 0.5% were invoked in concrete containing macro silica fume, SF. Compressive, indirect tensile, and flexural tests were conducted on HPFRC specimens after exposing them to previous media after 28 and 180 days of exposure. The test results in the present work indicated that the HPFRC containing steel fiber is more durable than the other one containing polypropylene fiber, especially when exposed to sodium chloride and magnesium sulfate media. Moreover, the optimum values for compressive strength of HPFRC are obtained when Vf equals 1.0% for steel fiber and 0.3% for polypropylene fiber. On the other hand, the optimum values for indirect tensile and flexural strengths of HPFRC are obtained when Vf equals 1.5% for steel fiber and 0.5% for polypropylene fiber.

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Keywords: *High performance fiber reinforced concrete, Hooked-end steel fibers, Polypropylene fiber, Compressive strength, Indirect tensile strength*

Farklı Çevresel Ortamlara Maruz Bırakılan Yüksek Performanslı Lif Takviyeli Beton (HPFRC) Durabilitesinin Değerlendirilmesi

Öz

Bu çalışmada, Yüksek Performanslı Elyaf Takviyeli Beton (HPFRC) dört farklı ortama maruz bırakıldıktan sonra mekanik ve durabilite özellikleri deneysel olarak incelenmiştir. Bu ortamlar hava, su, her ikisi de %7 konsantrasyonda sodyum klorür ve magnezyum sülfattır. 50 mm uzunluğunda kanca uçlu galvanizli çelik lif %0.5, %1.0 ve %1.5 olmak üzere üç farklı hacim fraksiyonunda (Vf), makro silis dumanı (SF) içeren betonda ise polipropilen lif %0.1, % 0.3 ve %0.5 hacim fraksiyonlarında kullanılmıştır. HPFRC numuneleri önceki ortamlara 28 ve 180 maruz kaldıktan sonra, basınç dayanımı, dolaylı çekme ve eğilme deneyleri gerçekleştirilmiştir. Mevcut çalışmadaki deney sonuçları, çelik lif içeren HPFRC'nin, özellikle sodyum klorür ve magnezyum sülfat ortamına maruz kaldığında, polipropilen lif içeren diğerine göre durabilitesinin daha iyi olduğunu göstermiştir. Ayrıca, HPFRC'nin basınç dayanımı için optimum değerler, Vf, çelik fiber için %1.0 ve polipropilen fiber için %0.3'e eşit olduğunda elde edilmiştir. Bununla birlikte, HPFRC'nin dolaylı çekme ve eğilme dayanımları için optimum değerler, Vf, çelik elyaf için %1.5 ve polipropilen elyaf için %0.5'e eşit olduğunda elde edilmiştir.

Anahtar kelimeler: *Yüksek performanslı elyaf takviyeli beton, Kancalı çelik elyaflar, Polipropilen elyaf, Basınç dayanımı, Dolaylı çekme dayanımı*

1. Introductıon

Reinforced concrete structures often crumble due to corrosion of steel reinforcement as a result of exposure to corrosive media. It has to serve for a long life span in a very harsh environment. With the development of fiber characteristics, such as durability and excellent mechanical properties, fiber has been used as an important addition to concrete. The fiber reinforced concrete has a perfect performance in mechanical properties and durability compared with plain concrete. Steel fiber (SF) and polypropylene fiber (PPF) outperform other fibers in terms of improving the properties of concrete and are widely used in practical engineering applications such as bridges, harbors, and road pavement. Several studies used various experimental methods to investigate the mechanical and durability properties of fiber- reinforced concrete (Polder & De Rooij, 2016). Köksal, Altun, Yiğit and Şahin (2008) studied the effect of silica fume with different percentages of 5, 10, and 15% with the addition of steel fiber 0.5 and 1% with an aspect ratio of 65 and 80 on compressive strength of FRC. It was found that the compressive strength values of concretes having an aspect ratio of 80 were higher than that of concretes with an aspect ratio of 65 for the same silica fume and steel fiber content. Experimental work for studying the effect of polypropylene fiber of concrete containing silica fume with different percentages of fiber on workability and durability of concrete was presented in Patel and Kulkarni's study (Patel & Kulkarni, 2012). The results showed that polypropylene fiber added to concrete has a slight effect on workability. Another experiment investigated the properties of concrete with the addition of polypropylene fiber on shear, tensile and compressive strength. The results noted that increasing polypropylene fiber has a little effect on compressive strength by the addition of fiber from 0.35% to 0.50% (Ahmed et al., 2006). The polypropylene fiber with ratios of 0%, 0.1%, 0.2%, 0.3% and 0.5% of cement weight has been used in Mashrei, Sultan and Mahdi's study. (Mashrei et al., 2018). The results show that the addition of polypropylene fiber to concrete influences compressive strength. The maximum compressive strength increased for mixes that contain fibers with a percentage of 0.2% of polypropylene fiber and a decrease in compressive strength when fiber percentage exceeds 0.2%. Gao, Sun, and Morino (1997) found that increasing fiber volume fraction led to increasing splitting tensile strength. It depends on aspect ratio and various fibers volume fractions. To get high splitting tensile strength volume fraction must exceed 1.0%. Song, Hwang, and Sheu (2005) examined polypropylene fiber reinforced concrete with a fiber content of 0,6 kg / m3. The splitting tensile strength improved. Islam and Gupta (2016) used polypropylene fiber with various contents. The results show that the addition of 0.1% of polypropylene fiber gave an increase in tensile strength compared to plain concrete. Hasan, Maroof and Ibrahim (2019) found that the addition of polypropylene fiber with a volume fraction of 0.36% causes an improvement in strength properties after 28 days. Flexural strength test specimens with a prismatic dimension of 100 x 100 x 500 mm were conducted in Rahmani, Kiani, Sami, Fard, Farnam, & Shekarchizadeh's study (Rahmani et al., 2011). Test procedure loading according to ASTM C1018 using third point loading. Three specimens were tested after 28 days. The average result shows that the addition of steel, glass, and polypropylene fibers with a volume fraction of 0.5%, 0.125%, and 0.125% respectively. The results show that the addition of fibers improves the flexural strength of concrete. Steel fiber reinforced concrete resistance to corrosion is governed by factors that affect the corrosion resistance of reinforced concrete such as chloride penetration ions, carbonation, and sulfate attack related to the permeability matrix of cement (Frazão et al., 2015). Researchers' results showed that ultra-high-performance fiber concrete (UHPC) which contains steel fibers has a high resistance to chloride penetration compared to plain concrete (Tayeh et al., 2012; Behfarnia & Behravan, 2014). The effect of steel fibers on chloride penetration resistance by using L = 32 mm and L/D = 53 was introduced in Anastasiou, Papayianni, and Papachristoforou's study (Anastasiou et al., 2014). As the volume fraction was 0.4, 0.6, and 0.8%, the penetration depth was reduced for SFRC compared to the control sample. Vegesana and Killamsetty (2020) studied the durability of steel fiber reinforced concrete and strength for end hooked type with dosage by weight of concrete 0.5%, 1.0%, and 1.5% with 60 aspect ratios. Specimens were tested after 7 and 28 days. The results show that steel fiber reinforced concrete had more resistance to sulfate attack and acid attack than conventional concrete. Krishna and Rao (2016) studied steel fiber reinforced concrete (SFRC) durability with a dosage of 0.5%, 1.0%, and 1.5% by volume of concrete. End hooked steel fibers are randomly dispersed in concrete. Cube specimens were immersed in sulfate acid with 3% for 28 days and 56 days. The addition of steel fiber was effective for acid resistance. Increasing the dosage of fiber led to a decrease in compressive strength. Basavaraj and Amaresh (2015) studied the durability of SFRC with a dosage of 0.75%, 0.1%, and 1.25% by volume and 54 aspect ratios. After 28 days of curing, the cubic specimens were removed from the curing tank and impressed in a 3% H_2SO_4 solution. SFRC is more resistant to acid attack compared to conventional concrete. A dosage of 1.25% gives a high resistance to acid attack. Vegesana and Killamsetty (2020) studied the behavior of reinforced concrete with steel fiber exposed to chemical attack with a concentration of 5% for H_2SO_4, $MgSO_4$, and NaCL solutions in both control and SFRC. The results show that loss of compressive strength and weight for H_2SO_4 is higher than $MgSO_4$ and NaCL. Rajak and Rai (2019) studied the effect of polypropylene fiber concrete specimens after being submerged in 5% sulfuric acid solution of H_2SO_4 at different periods. Removing specimens from H_2SO_4 solution after 56 days, some minor spalling action of chemicals was noted <1mm thick around the attacked area. The loss weight for polypropylene fiber is significantly smaller compared to ordinary Portland cement concrete when exposed to 5% H_2SO_4 solution. Nair and Varghese (2017) investigated the effect of polypropylene fiber by casting and curing cube specimens with dimensions of 150 x 150 x 150 mm for 28 days. Sulfate attack was tested using 5% $MgSO_4$. The specimens were immersed in $MgSO_4$ for 56 days. After reaching 56 days, specimens were raised from solution, then the surface of the specimens was cleaned and weight was measured. Specimens were tested in a compression testing machine. The results showed that the compressive strength slightly decreased. The mechanical and durability properties of HPFRC were investigated experimentally in this study by exposing it to four different media. Air, water, sodium chloride, and magnesium sulfate with 7% concentration were used. Hooked-end galvanized steel fiber 50mm length with volume fraction, Vf, 0.5%, 1.0%, and 1.5% and polypropylene fiber with Vf, 0.1%, 0.3%, and 0.5% were invoked in concrete containing macro silica fume, SF, and Master Glenium RMC 315 as superplasticizer.

2. Experimental Works

The main purpose of this research is to experimentally study the durability of HPFRC with different types of fibers exposed to different environments like air, water, chlorides, and sulfates. The evaluation of the effect of these environments is based on the mechanical properties of compressive, indirect tensile and flexural tests. The experimental program includes the investigation of the durability of steel fiber concrete and polypropylene fiber concrete after exposing to these media for 28 and 180 days.

2.1 Materials

The fine aggregate used in the concrete mix was natural siliceous sand with good quality and free from impurities. Physical properties and sieve analysis of sand was determined as shown in Table 1 and Table 2.

Table 1. Physical properties of sand

Property	Measured value	Egyptian code limits
Compactd density	1795 kg/ m^3	———
Loose density	1700 kg/m^3	———
Specific gravity	2.60	———
Fine material	1.5 %	2.5 %

The nominal maximum size of used dolomite was 14 mm as coarse aggregate. Sieve analysis is shown in Table 3 and physical properties are shown in Table 4. The dolomite was washed and immersed carefully in water to be fully saturated and then dried well over a sieve at room temperature before mixing.

Table 2. Sieve analysis of sand

Sieve opening, mm	Passing %	General limits*
5	98.9	89-100
2.36	95.4	60-100
1.18	80.5	30-100
0.6	40.6	15-100
0.3	25.9	5-70
0.15	8.2	0-15

*Egyptian code No.203/2020

Table 3. Sieve analysis of dolomite

Sieve opening, mm	Passing %	General limits*
50	100	-
37.5	100	-
20	100	100
14	98.1	85-100
10	40.5	0-50
5	3.8	0-10
2.36	0	-

Table 4. Physical properties of dolomite

Property	Measured Value	Egyptian Code Limit
Specific gravity	2.6	—
Unit weight, t / m^3	1.48	—
Absorption %	.85%	2 %
Organic materials	None	0.05-0.1 %

*Egyptian code No.203/2020

The used water in all mixes was fresh water, free from impurities and clean drinking water. The used water/cement ratio was 0.35 for all mixes. Portland cement CEMI with grade 52.5 N Sinai Company was used in this work. The physical properties of used cement are illustrated in Table 5 according to Egyptian standard specification.

Silica fume had a particle size of 0.7 µm and a bulk density of 345 kg/m3. Silica fume was added by a percentage of cement weight to the mix. It added 15% of the cement weight. A high range water reducer (HRWR) of the third generation called Master Glenium 315C with properties listed in Table 6 was used.

Hooked end steel fiber used in this work is shown in Fig 1. Steel fiber has length of 50 mm with .5 mm diameter and modulus of elasticity of 200 GPa. The aspect ratio (L/D) was 100. The properties of used steel fiber are given in

Table 7. Fiber volume fractions with Vf = 0.5%, 1.0% and 1.5% were used.

Table 5. Physical properties of cement

Property	Test result	E.S.S 4756-1/2013
Specific gravity	3.15	-
Setting time		
Initial [min.]	90 min.	≥ 45 min.
Final [hr.]	4.35 hr.	———
Fineness	3300 cm^2/gm*	———
Compressive strength [MPa]		
2 days	30 MPa	≥ 20 MPa
28 days	65 MPa	≥ 52.5 MPa
* Sinai company Results.		

Table 6. Physical properties of Glenium as per the manufacturer data sheet**

Product data	
Appearance	Off white opaque liquid
Specific gravity	1.1 g/cm3
PH-value	6.5 ± 1
Alkali content (%)	≤ 2.00 by mass
Chloride content (%)	≤ 0.10 by mass
Air content	Fulfilled
Water reduction	≥ 112% of Reference mix
**Certificate No. 0086-CPD-469071 EN 934-2: T3.1&T3.2	

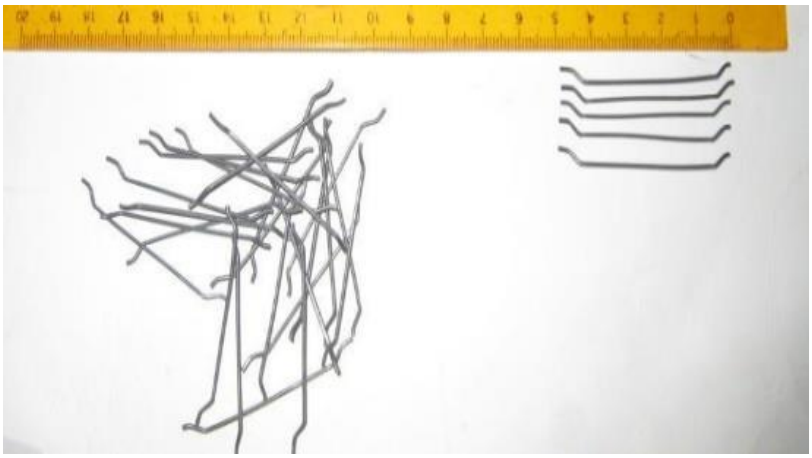

Figure 1. The hooked end steel fiber.

Table 7. Properties of the hooked-end steel fiber.

Property	Value
Type	Hocked end
Specific gravity	7.8
Tensile strength	400-800 MPa
Crimped height	2 – 3 mm
Length	50 mm
Diameter	.5 mm
Aspect ratio	100
Modulus of Elasticity	200 GPa

Polypropylene fiber is an additive fiber to reduce the occurrence of plastic shrinkage and plastic settlement cracking, whilst enhancing the surface properties and durability of hardened cementitious products. It was supplied by Sika Company as shown in Fig 2. The properties of used polypropylene fiber are given in Table 8. Fiber volume fraction values of Vf = 0.1%, 0.3% and 0.5% were used.

Figure 2. The polypropylene fiber.

Table 8. Properties of the polypropylene fiber

Property	Value
Type	Sika Fiber
Density	.91 gm nominal
Tensile strength	300-400 N/mm^2
Length	18mm
Melt point	160 ^{0} c
Specific surface area	250 m2/kg
Modulus of elasticity	4000 N/mm^2

3. Mix Proportion and Design

The mix proportions of all test specimens were given in Table 9 by using the absolute volume method. The fibers were added to the mix as a ratio of its volume by the percentages illustrated in the experimental program and silica fume was added as a percentage of cement weight.

Table 9. Mix proportions

Mix items	Amount	Ratio
Cement (kg/m^3)	500	1
Silica fume (kg/m^3)	75	
Sand (kg/m^3)	750	1.31
Dolomite (kg/m^3)	1000	1.74
Water (lit/m^3)	201	0.35
Superplasticizer (lit/m^3)	10	0.017

4. Specimens Details, Mixing, Curing and Testing

The total numbers of specimens casted for testing are 168, as follows, 84 specimens casted for 28 days and 84 specimens casted for 180 days. Each media consists of 7 fiber ratios and every fiber ratio comprising of 3 specimens and the average value is reported. 168 cylindrical specimens with dimensions of 100 mm diameter and 200 mm height were casted for indirect tension test. The specimens were divided like cubes. 168 beam specimens with dimensions of 100 x 100 x 500 mm for flexural test were, also, casted and divided like cubes and cylinders. The constituent materials were initially mixed without fibers.. The fibers were then added in small amounts to avoid fiber balling and to produce concrete with uniform material consistency and good workability then compacted on a vibration table. The slump test was performed to measure the workability of the concrete mix in this work. The slump value was 6 cm for control specimens. No sign of segregation was detected and the mixture showed good homogeneity and cohesion. It was observed that using fiber decreases the value of the slump than control specimens. The slump value for fiber concrete was 5 cm. The specimens were demolded after 24hours from the time of casting and cured in tap water for 28-days at room temperature conditions. After that specimens were placed in different media for a period of 28 and 180 days. Those media were prepared as follows: water media consists of basins filled with drinking water, air media is at room temperature on the ground, the sulfate media consists of basins containing solutions of 7% magnesium sulfate, and the chloride media consists of basins containing solutions of 7% sodium chloride. The solution was changed after 3 months to keep constant concentration during the storage duration. Three standard tests were used to measure the mechanical properties of specimens.

A universal testing machine with a maximum capacity of 1000 kN was used. Figures 3, 4 and 5 showed the test setup for compressive strength, indirect tensile strength, and flexural strength in accordance with ASTM C-109, ASTM C-496 and ASTM C-78, respectively.

Figure 3. Compressive Strength Test.

Figure 4. Indirect Tensile Strength Test.

Figure 5. Flexural Strength Test.

5. Results And Discussion

5.1 Compressive Strength

The results shown in Figures 6 and 7 indicate that using steel fiber in high performance concrete containing silica fume led to improve compressive strength. The maximum values of compressive strength were obtained at 1.0% fiber ratio where an improvement by 20% and 19.7% was reported as compared with that of control specimens after 28 and 180 days, respectively. This improvement is more pronounce when concrete was cured in clean water This result is in agreement with the results of Köksal et al. (2008) and Balu, S. (2015), where they found that the highest compressive strength obtained at volume fraction of about 1.0%, which is about 13.8% and 5.6% respectively. Moreover, one can notice that, the results in figures 6 and 7 approved that the sulfate media is the most aggressive media for the compressive strength of concrete. With the volume fraction of steel fiber increased to 1.5%, the compressive strength in all media was decreased with severe rate especially in sulfate media at 180 days. The enhancement in compressive strength with addition of steel fiber in these media can be attributed to the confinement effect of fibers that increases the stiffness of concrete, the resistance of cracking to the propagation of micro and macro-cracks and the ability of steel fibers to add cohesion between the components of the concrete mixture and also give additional strength and resistance to concrete under the influence of applied loads.

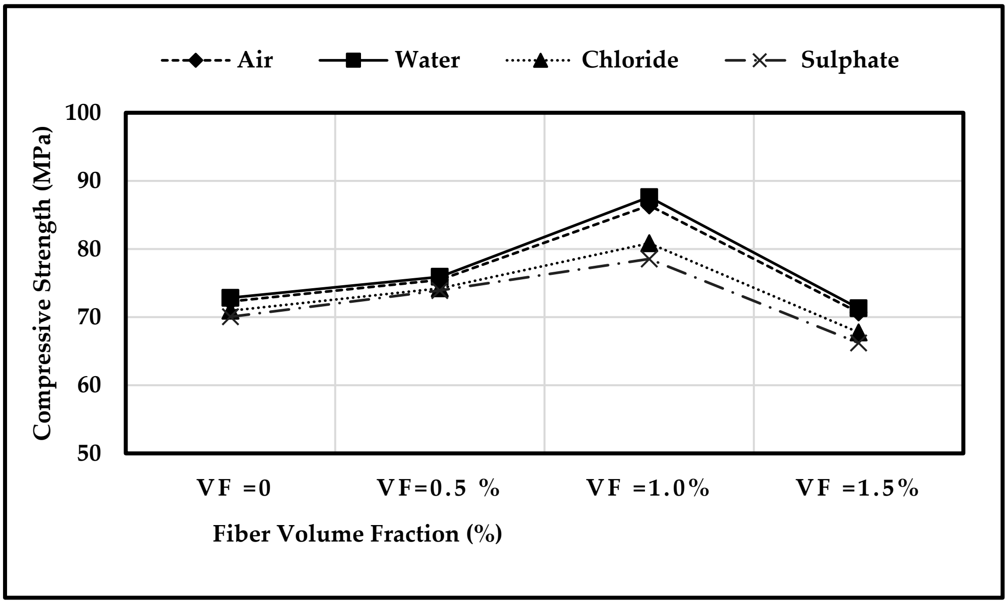

Figure 6. Compressive strength for steel fiber concrete after 28 days.

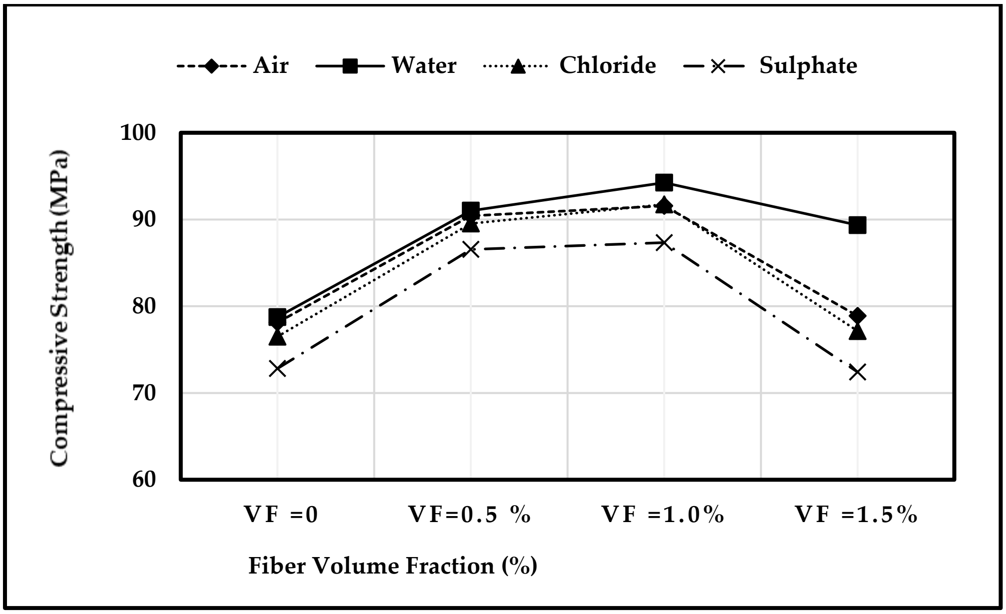

Figure 7. Compressive strength for steel fiber concrete after 180 days.

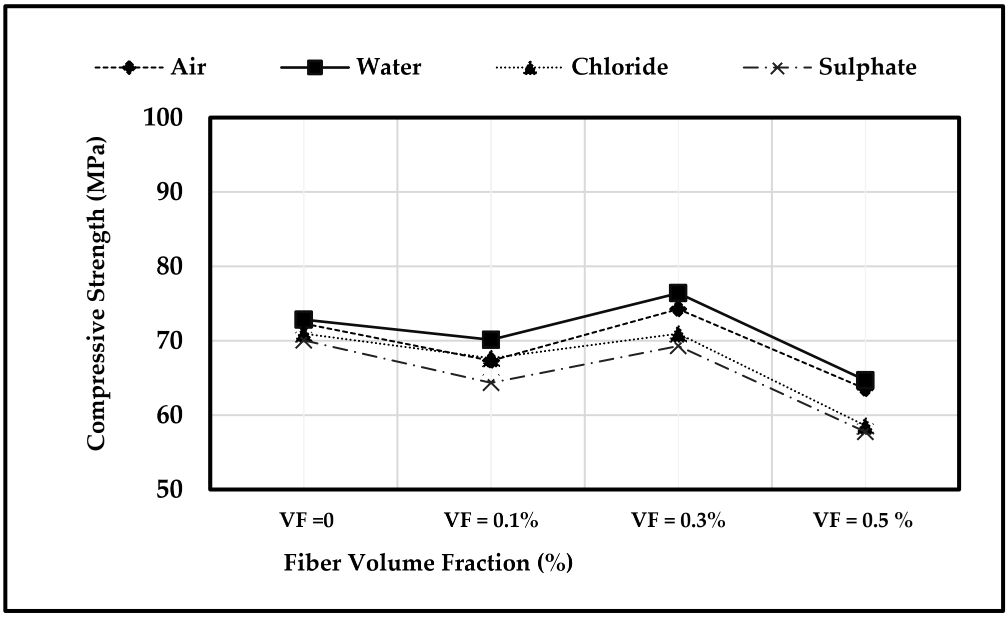

Figure 8. Compressive strength for Polypropylene fiber concrete after 28 days.

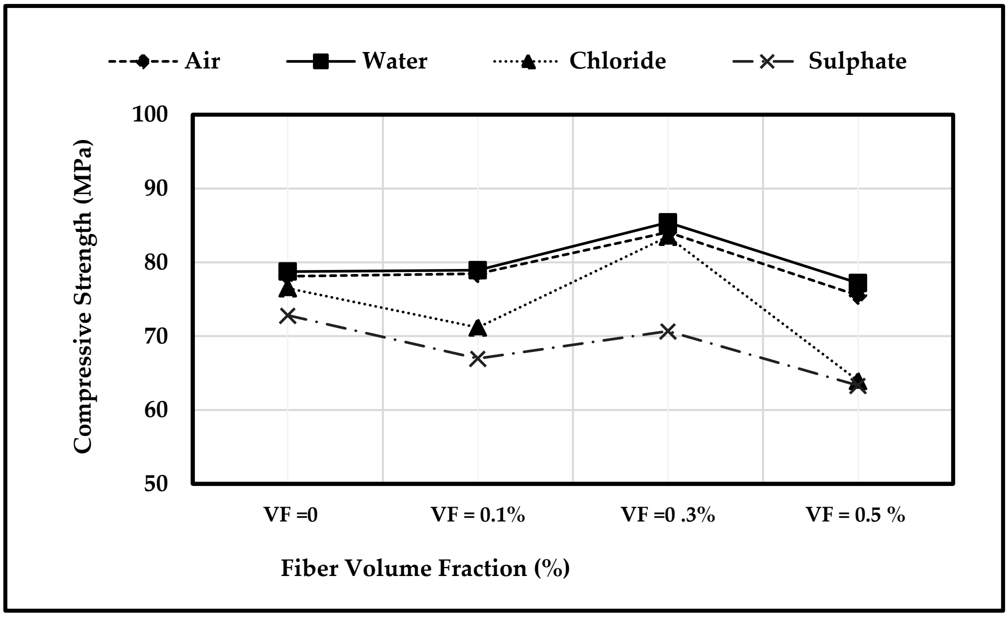

Figure 9. Compressive strength for Polypropylene fiber concrete after 180 days.

Figures 8 and 9 shows that using polypropylene fiber with a volume fraction of 0.1% did not improve compressive strength after 28 days compared to the steel fibers and there is a slight improvement of 4.8% when using a 0.3% volume fraction and curing in clean water after 28 days. Likewise, after 180 days, the improvement in compressive strength was 8.4% at a 0.3% volume fraction. This result is in agreement with the result of Ahmed. S. et al. [6] where it is noted that the addition of polypropylene fiber from 0.35% to 0.5% has a little effect on compressive strength. By comparing the results of compressive strength for HPFC in different media, it is clear that steel fibers improve compressive strength in all media, but in different proportions, and the ratio of 1.0% is the optimal ratio. While the propylene fibers did not lead to a noticeable improvement in compressive strength in different media, and the percentage of 0.3% gave a slight improvement rate compared to the steel fibers.

5.2 Indirect Tensile (Splitting) Strength

The results shown in Figures 10 and 11 indicate that using steel fiber in high performance concrete containing silica fume led to improve indirect tensile strength after 28 and 180 days. It is noted that increasing fiber ratio in the concrete leads to an increase in the indirect tensile resistance. The maximum value obtained at 1.5% volume fraction were 94% and 143% with respect to control specimens after 28 and 180 days, respectively. This improvement is clearly when concrete is cured in clean water. This result is in agreement with the result of Jianming Gao et al. [8] where it is found that increasing volume fiber fraction from

0% to 2.0% led to increasing splitting tensile strength from 4.95 to 8.8 MPa due to the increase in the bonding between the components of the concrete mixture by increasing the percentage of fibers in the concrete mixture, which in turn delays the appearance of cracks and reduces their width. The fibers also have a great role in forming connecting bridges in the crack area, which helps the section to increase the bearing and create additional resistance.

Using polypropylene fiber, as shown in figures 12 and 13, did not improve indirect tensile strength after 28 days compared to the steel fibers. On the hand, the values of indirect tensile strength improved by 55.6% with respect to control specimens when using a 0.5% volume fraction and curing in clean water after 180 days. From the previous results, the indirect tensile strength for HPFC in different media increased with increasing volume fiber fraction and steel fiber improve indirect tensile strength than polypropylene fiber in all media, but in different proportions, and the ratio of 1.5% steel fiber gave a maximum value for indirect tensile strength.

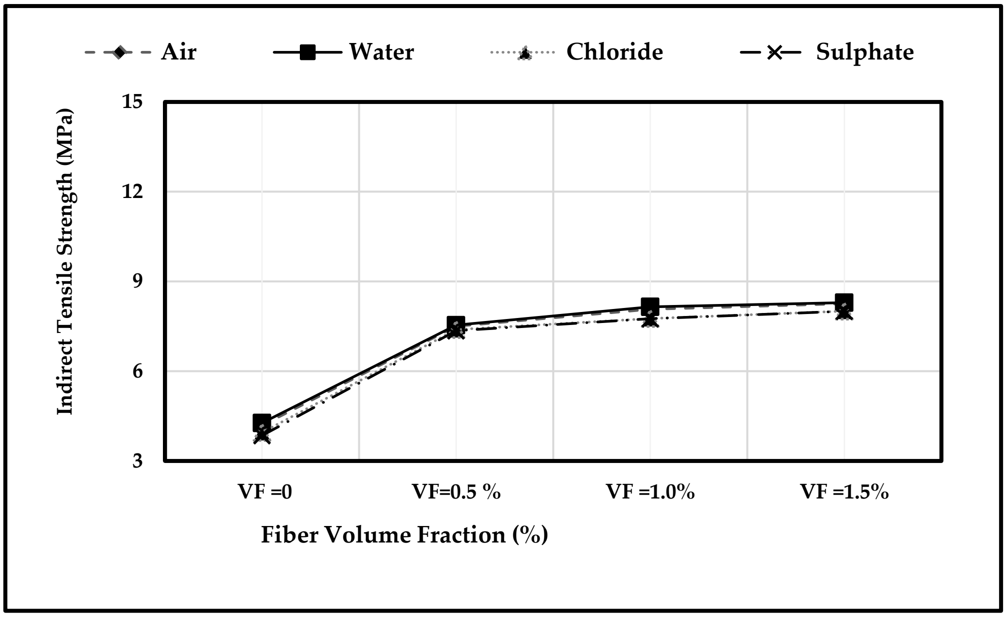

Figure 10. Indirect Tensile strength for steel fiber concrete after 28 days.

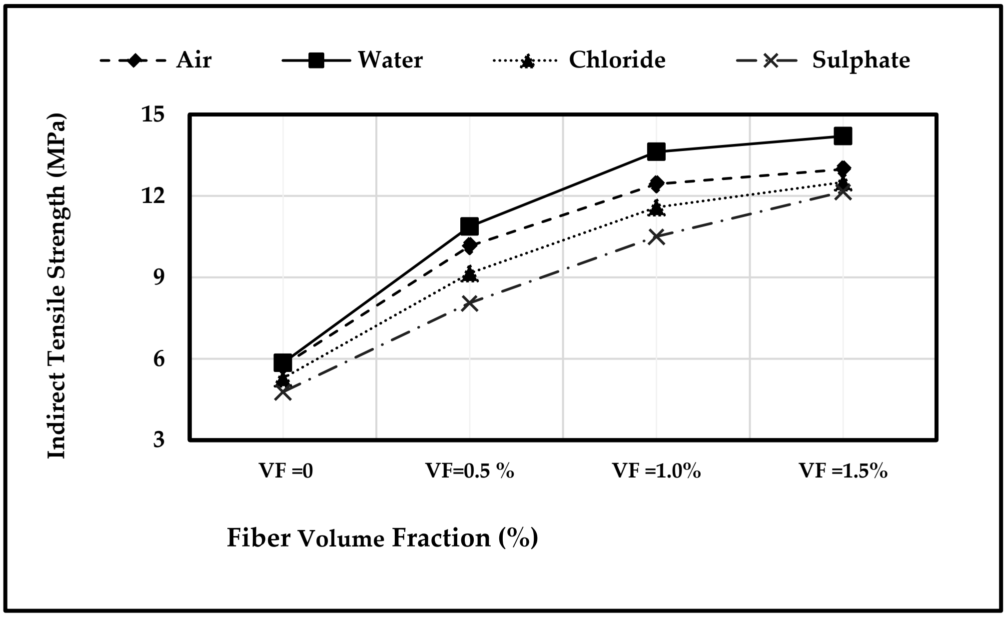

Figure 11. Indirect Tensile strength for steel fiber concrete after 180 days.

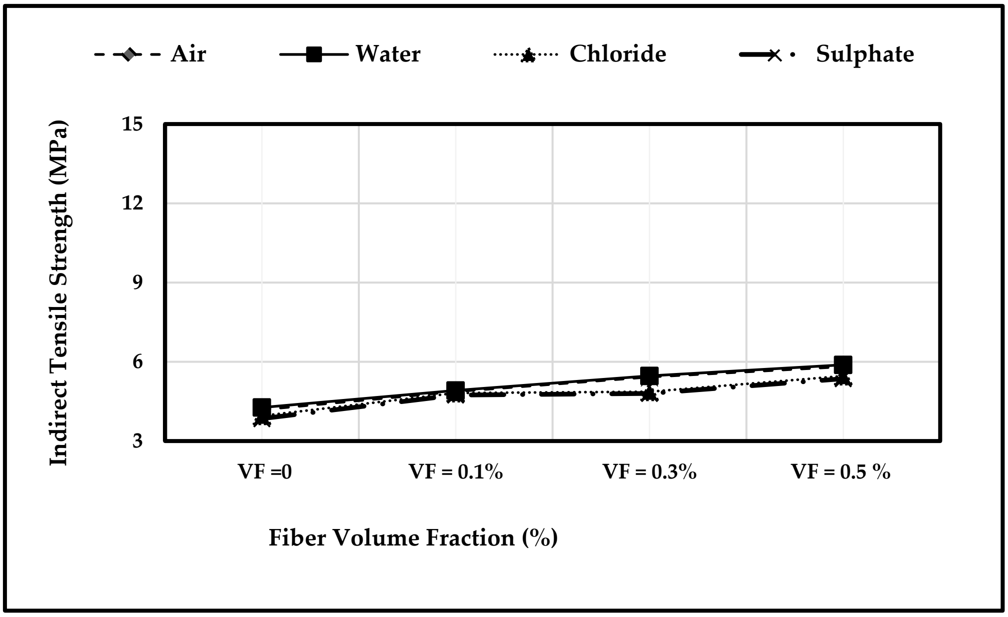

Figure 12. Indirect Tensile strength for Polypropylene fiber concrete after 28 days.

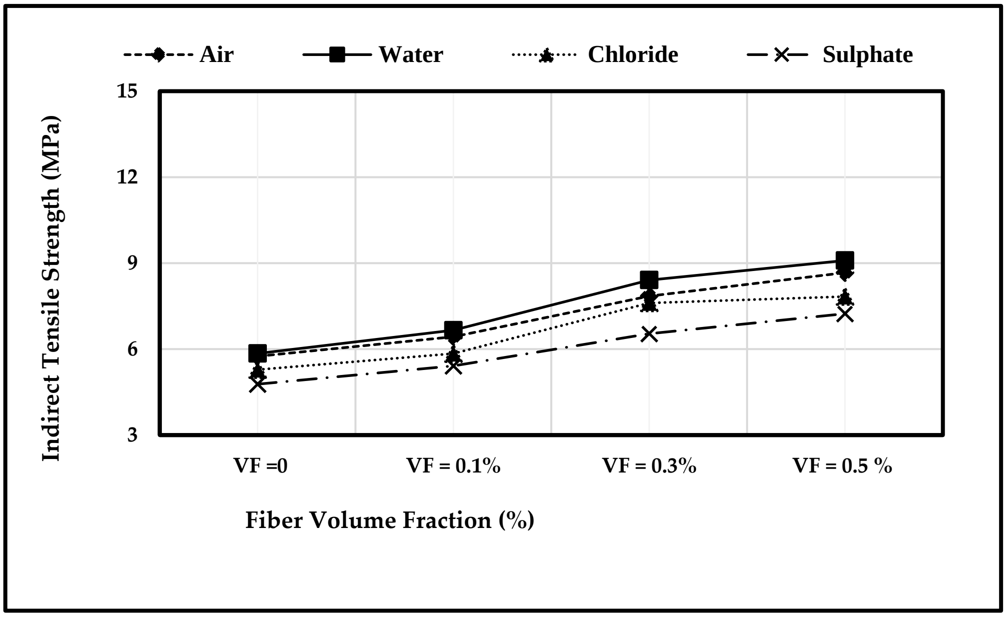

Figure 13. Indirect Tensile strength for Polypropylene fiber concrete after 180 days.

5.3 Flexural Strength

From the results shown in Figures 14 and 15, one can notice that, the experimental results for flexural strength of steel fiber reinforced concrete in different media were improved after 28 and 180 days with increasing the fiber ratio in the concrete. The maximum value obtained at 1.5% volume fraction was 47.8% and 21% with respect to control specimens after 28 and 180 days when concrete is cured in clean water. This result is in agreement with the result of T. Rahmani et al. [12] where it is found that the addition of steel fiber volume fraction led to improving flexural strength. This is due to the ability of steel fibers to significantly increase the flexibility and durability of the concrete section, thus giving it the ability to reach maximum resistance. The data presented in Figure 16 shows that using polypropylene fiber improves flexural strength after 28 days in all media for all fiber volume fractions. On the hand, the flexural strength in all media showed a remarkable decreasing at Vf equals 0.1% and after 180 days as shown in Figure 17. After that the flexural strength starts to increase with the increase of the volume fraction of polypropylene fiber content up to 0.5%. The maximum value obtained at 0.5% volume fraction was 29.6% increase with respect to control specimens in sulfate media.

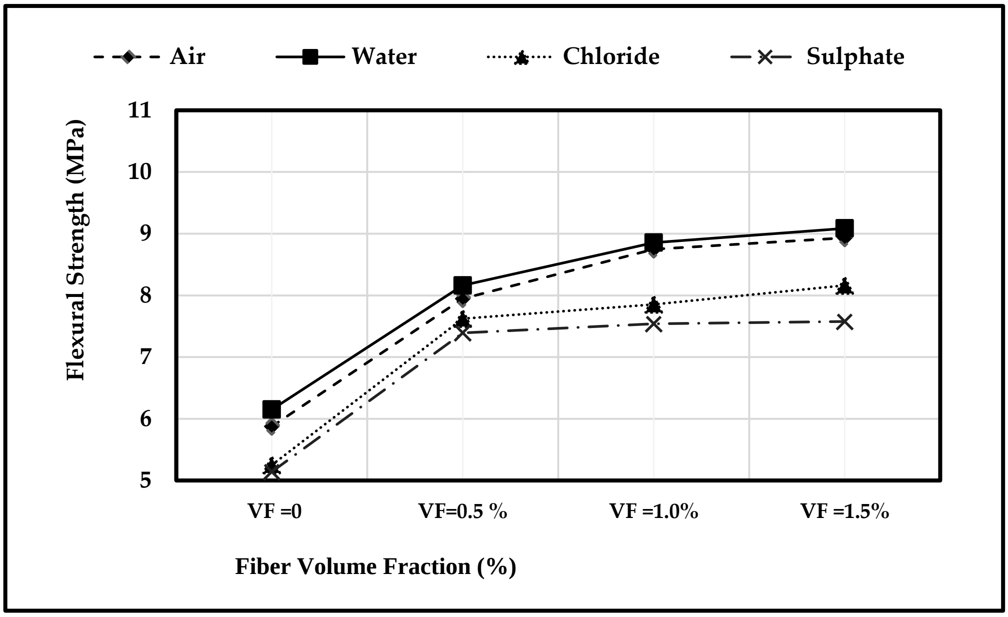

Figure 14. Flexural strength for steel fiber concrete after 28 days.

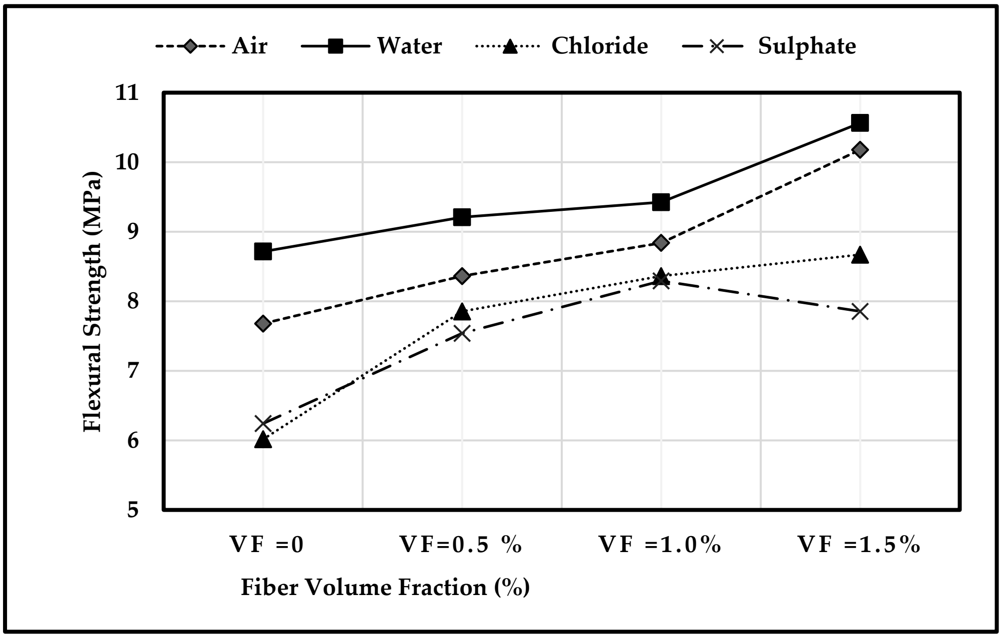

Figure 15. Flexural strength for steel fiber concrete after 180 days.

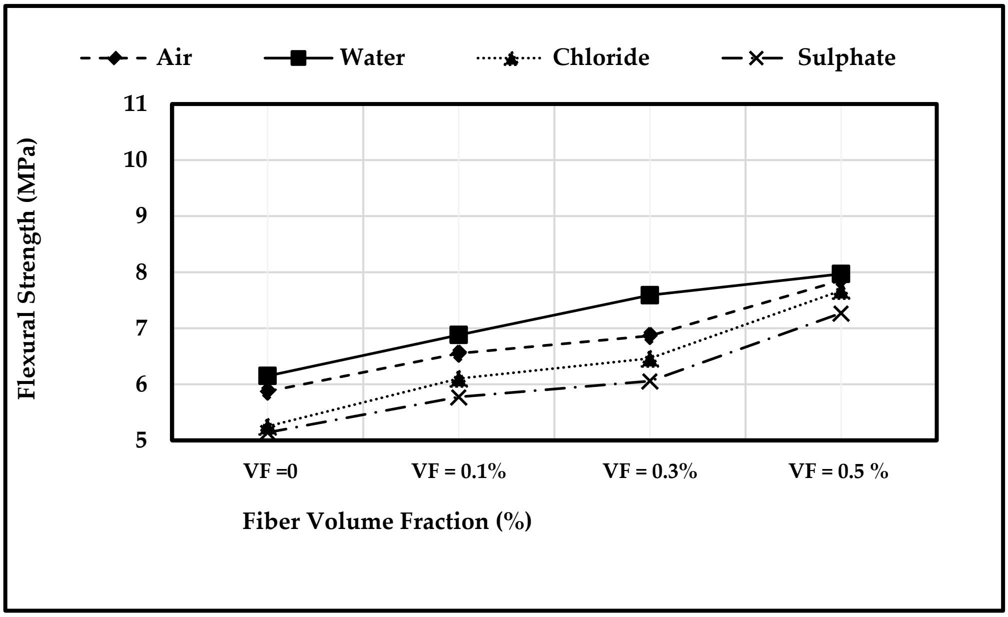

Figure 16. Flexural strength for Polypropylene fiber concrete after 28 days.

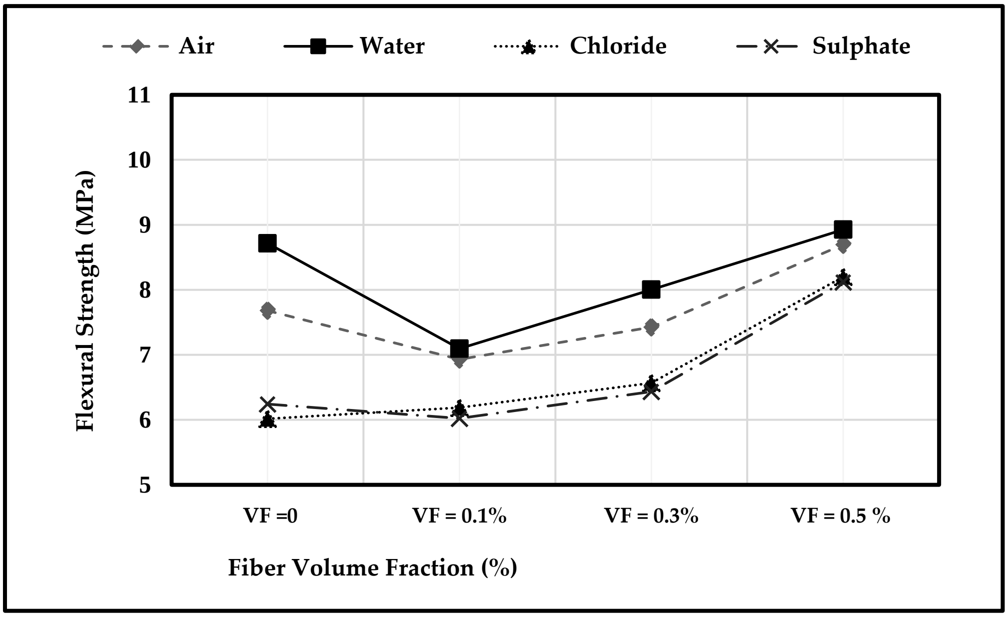

Figure 17. Flexural strength for Polypropylene fiber concrete after 180 days.

6. Conclusions

This study presents an experimental program to investigate the effect of steel and polypropylene fiber on compressive strength, indirect tensile strength and flexural strength with various volume fraction at different environmental media for different storage time.

From the obtained results, it can be concluded the following main points:

1- The optimum fiber volume fraction, Vf, in case of steel fiber concrete was 1.0% for compressive strength and 1.5% for indirect tensile and flexural strengths. While the optimum fiber volume fraction, Vf, in case of polypropylene fiber concrete was 0.3% for compressive strength and 0.5% for indirect tensile and flexural strengths.

2- At the optimum Vf, 1.0%, for steel fiber concrete the compressive strength at 180 day was found to decrease from 85.4 MPa, for water media, to 84.08 MPa, to 83.48 MPa and to 70.86 MPa for air, chloride, and sulfate media respectively.

3- For polypropylene fiber concrete and at optimum Vf, the concrete compressive strength at 180 day was found, also, to decrease from 94.24 MPa, for water media, to 91.74 MPa, to 91.57 MPa and to 87.33 MPa for air, chloride, and sulfate media respectively.

4- At the optimum Vf, 1.0%, for steel fiber concrete the indirect tensile strength at 180 day was found to decrease from 14.4 MPa, for water media, to 12.98 MPa, to 12.5 MPa and to 12.12 MPa for air, chloride, and sulfate media respectively.

5- For polypropylene fiber concrete and at optimum Vf, the concrete flexural strength at 180 day was found, also, to decrease from 8.93 MPa, for water media, to 8.7 MPa, to 9.2 MPa and to 8.12 MPa for air, chloride, and sulfate media respectively.

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