Scientific Review Engineering and Environmental Sciences (2022), 31 (2), 88–100

Sci. Rev. Eng. Env. Sci. (2022), 31 (2) https://srees.sggw.edu.pl

ISSN 1732-9353 (suspended) eISSN 2543-7496 DOI 10.22630/srees.2946

Received: 04.04.2022
Accepted: 27.05.2022

DURABILITY OF HYBRID FIBER REINFORCED CONCRETE AT VARIOUS ENVIRONMENTAL MEDIA

Eslam Ibrahim Nasr ELHAWARY[1] ✉ https://orcid.org/0000-0001-6516-2156

Ashraf Hassan ELSAFOURY[2] https://orcid.org/0000-0001-6615-3083

Seleem Saleh Elsayed AHMAD[3] https://orcid.org/0000-0001-9894-0209

[1] Misr Higher Institute of Engineering and Technology, Egypt
[2] Zagazig Higher Institute of Engineering and Technology, Egypt
[3] Zagazig University, Faculty of Engineering, Egypt

Key words: durability, hybrid fiber concrete, steel fibers, polypropylene fibers, compressive strength, splitting tensile strength, flexural strength

Introduction

The main objective of the research is to study the durability of hybrid concrete in various media. Reinforced concrete elements exposed to the sea environment have been studied by many researchers and found that concrete structure constructed in the ocean environment are severely eroded for many reasons before achieving their design service life. Some of them cracked over time and need to be repaired and some of them collapsed and need to be reconstructed due to the exposure of these facilities to sulphates and chlorides (Val & Stewart). Using normal concrete cannot achieve the durability requirement for concrete structure in a harsh environment, therefore using special concrete that resists seawater and has long-life serviceability is recommended. Developing construction materials has generated a requirement for concrete with toughness, high strength, and durability. An example of durable concrete with strength is high-performance concrete reinforced with fiber which could be used to achieve mechanical properties compared with traditional concrete (Muigai, Moyo & Alexander, 2012; Kim, Hossain & Zhang, 2013; Cwirzen, Sztermen & Habermehl-Cwirzen, 2014; Demirel, Gultekin &Alyamaç, 2019). Some researchers studied the effect of hybridization for fibers on concrete properties. The main purpose of using hybrid fibers is to control different zones of cracking for concrete, at different size levels, at multiple loading, and various curing ages (Qian & Stroeven, 2000a).

✉islamelhwary@yahoo.com

Mohammadi, Singh and Kaushik (2008) investigated the influence of steel fiber additions with various aspect ratios on concrete compressive strength. With a volume proportion of 2%, two types of fibers were used: 65% long fiber and 35% short fiber. The splitting tensile strength of concrete was found to rise by up to 59%. Steel fibers of various lengths with fiber contents of 1.0, 1.5, and 2.0%. The results showed that compressive strength increased from 3 to 26% by using fiber. As observed in other studies, adding fiber led to a reduction in compressive strength as was observed in other studies (Bencardino, Rizzuti, Spadea & Swamy, 2008; Atiş & Karahan, 2009; Khitab et al., 2013). The main reason for the reduction in compressive strength is the dispersion of the fibers, especially in concretes with a high fiber content, which causes poor workability (Noushini, Samali & Vessalas, 2013). Dawood and Ramli (2011) experimented on high-strength mortar reinforced with hybrid fibers. It was found that hybrid fibers led to an increased modulus of elasticity by 52% for concrete. Yao, Li and Wu (2003) investigated the effect of low fibers volume fraction. Adding steel and carbon fibers led to an increase in splitting tensile strength, whereas using polypropylene fibers resulted in a reduction in indirect tensile strength. Hybridization of steel with carbon fibers resulted in high indirect tensile strength, this was superior to using steel or carbon fibers separately (Yu, Spiesz & Brouwers, 2014). Hybridization of two or more fibers with different types and sizes can improve more properties of concrete (Cattaneo & Biolzi, 2010; Yang, 2011; Banthia, Majdzadeh, Wu & Bindiganavile, 2014). Qian and Stroeven (2000b) evaluated the effect of adding different polypropylene and steel fibers to reinforced specimens with fiber content ranging from 0.4 to 0.95% on flexural performance. In the small displacement range of hybrid fiber reinforced concrete, it was discovered that hooked end steel fiber $L = 40$ mm and $D = 0.3$ mm, as well as employed polypropylene fiber length $L = 12$ mm, had a substantial impact on load-bearing capacity. Sivakumar and Santhanam (2007) discovered that combining glass, polypropylene, or polyester fibers with steel fiber improved the performance of fiber reinforced concrete compared to concrete without fibers. Blunt and Ostertag (2009) have demonstrated that utilizing hybrid fibers significantly improved the flexural behavior of concrete when compared to a single fiber composite. The result of fiber hybridization led to increased flexural strength of up to 196% relative to the control specimens. Orouji, Zahrai and Najaf (2021) found that using 25% glass powder and 1.5% polypropylene fiber led to improves the compressive strength, flexural toughness, and ductility in the beams by about 1.6, 4, and 13.2 times, respectively.

Najaf, Orouji and Zahrai (2022) investigated the effect of waste glass powder, nanosilica, and recycled polypropylene fiber on lightweight concrete and they found that the best sample had 1.5% fiber, 3% nanosilica, and 25% waste glass powder, and had compressive and tensile strengths of roughly 1.7 and 1.6 times, respectively, those of the control specimen after 28 days.

Steel and polypropylene fibers are used in the experimental program. This paper investigated the mechanical properties with two-volume ratios subjected to four various media air, water, sodium chloride, and magnesium sulphate with a 7% concentration. In the present work, steel and polypropylene

Elhawary, E. I. N., Elsafoury, A. H., Ahmad, S. S. E. (2022). Durability of hybrid fiber reinforced concrete at various environmental media. *Sci. Rev. Eng. Env. Sci.*, *31* (2), 88–100. DOI 10.22630/srees.2946

fibers are used for hybrid performance, the mechanical properties of hybrid fiber concrete are being investigated subjected to four various media: air, water, sodium chloride, and magnesium sulphate with 7% concentration.

Experimental works

The most important purpose of this research is to experimentally study the durability of high performance fiber reinforced concrete with different types of fibers exposed to different environments like air, water, chlorides, and sulphates.

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 exposure to these media for 28, 180, and 360 days.

Materials

Natural siliceous sand was used as a fine aggregate in the concrete mix with good quality and free from impurities. Physical properties of sand according to Egyptian code (Housing and Building National Research Center [HBNC], 2020) and sieve analysis of sand were determined (Tables 1 and 2).

The nominal maximum size of used dolomite was 14 mm as coarse aggregate. Physical properties of dolomite according to Egyptian code (HBNC, 2020) and sieve analysis of dolomite were determined (Tables 3 and 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 1. Physical properties of sand

Property	Measured value	Limit acc. to the ECP 203 standard (HBNC, 2020)
Compacted density [$kg \cdot m^{-3}$]	1 795	–
Loose density [$kg \cdot m^{-3}$]	1 700	–
Specific gravity	2.60	–
Fine material [%]	1.5	2.5

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

TABLE 3. Physical properties of dolomite

Property	Measured value	Limit acc. to the ECP 203 standard (HBNC, 2020)
Specific gravity	2.6	–
Unit weight [$t \cdot m^{-3}$]	1.48	–
Absorption [%]	0.85	2
Organic materials [%]	none	0.05–0.1

TABLE 4. Sieve analysis of dolomite

Sieve opening [mm]	Passing [%]	General limits
50	100	–
37.5	100	–
20	100	–
14	98.1	85–100
10	40.5	0–50
5	3.8	0–10
2.36	0	–

Used water in all mixes was fresh water, free from impurities, and clean drinking water. The used water to cement ratio was 0.35 for all mixes. Portland cement CEM I with grade 52.5 N (producer Sinai White Portland Cement Company) was used in this work. Physical properties of used cement are illustrated in Table 5 according to Egyptian standard specifications (Egyptian Organization for Standardization and Quality Control [EOS], 2013).

TABLE 5. Physical properties of cement

Property	Test result	Value acc. to the ESS 4756-1 standard (EOS, 2013)
Specific gravity	3.15	–
Setting time		
initial [min]	90	≥ 45
final [h]	4.35	–
Fineness [$cm^2 \cdot g^{-1} \cdot m^{-1}$]	3 300*	–
Compressive strength after [MPa]		
2 days	30	≥ 20
28 days	65	≥ 52.5

*Sinai White Portland Cement Company results.

Silica fume had a particle size of 0.7 µm and a bulk density of 345 $kg \cdot m^{-3}$. 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 of the third generation called MasterGlenium® RMC 315 (producer BASF SE) with properties listed in Table 6 was used.

Hooked-end steel fiber used in this work is shown in Figure 1. Steel fiber has a length of 35 mm with a 0.8 mm diameter and modulus of elasticity of 200 GPa. The aspect ratio (*L*/*D*) was 43.75. The properties of used steel fiber (supplier Nassar Group Egypt) are given in Table 7. Fiber volume fractions (V_f) of 0.5, 1, and 1.5% were used.

TABLE 6. Physical properties of MasterGlenium® RMC 315* (based on product data sheet)

Property	Value / Description
Appearance	off white opaque liquid
Specific gravity [$g \cdot cm^{-3}$]	1.1
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 0086-CPD-469071 EN 934-2: T3.1&T3.2.

FIGURE 1. Used steel fiber

TABLE 7. Properties of used steel fiber (based on product data sheet)

Property	Value / Description
Type	hocked end
Specific gravity	7.8
Tensile strength [MPa]	1 100
Crimped height [mm]	2.1–2.9
Length [mm]	35
Diameter [mm]	0.8
Aspect ratio	43.75

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 the Sika AG as shown in Figure 2. The properties of used polypropylene fiber are given in Table 8. Fiber volume fraction (V_f) of 0.1, 0.3, and 0.5% were used.

FIGURE 2. Used polypropylene fiber

TABLE 8. Properties of used polypropylene fiber (based on product data sheet)

Property	Value / Description
Type	SikaFiber®
Density [$g \cdot m^{-1}$ nominal]	0.91
Tensile strength [$N \cdot mm^{-2}$]	300–400
Length [mm]	18
Melt point [°C]	160
Specific surface area [$m^2 \cdot kg^{-1}$]	250
Modulus of elasticity [$N \cdot mm^{-2}$]	4 000

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 their volume by the percentages illustrated in the experimental program and silica fume was added as a percentage of cement weight.

TABLE 9. Mix proportions of tested specimens

Mix items	Amount	Ratio
Cement	500 $kg \cdot m^{-3}$	1
Silica fume	75 $kg \cdot m^{-3}$	
Sand	750 $kg \cdot m^{-3}$	1.31
Dolomite	1 000 $kg \cdot m^{-3}$	1.74
Water	201 $l \cdot m^{-3}$	0.35
Superplasticizer	10 $l \cdot m^{-3}$	0.017

Specimens details, mixing, curing, and testing

In this study cubic specimens with dimensions 100 × 100 × 100 mm were cast for a compression test, for indirect tension testing, cylinder specimens with a diameter of 100 mm and a height of 200 mm were used, and beam specimens with dimensions of 100 × 100 × 500 mm were used for flexural load testing with two loads at third points over a simply supported span of 400 mm. The basic elements were initially blended without fibers for the creation of this concrete. To avoid fiber balling and generate concrete with a homogeneous material consistency and good workability, the fibers were added in modest amounts. Then compacted on a vibration table. In this work, the slump test was used to determine the workability of the concrete mix. There's no indication of segregation, and the mixture was homogeneous and cohesive. It was observed that using fiber decreases the value of the slump than control specimens.

The specimens were demolded after 24 h 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, 180 and 360 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 sulphate media consists of basins containing solutions of 7% magnesium sulphate, and the chloride media consists of basins containing solutions of 7% sodium chloride. The solution was changed after three months to keep constant concentration during the storage duration. The mechanical characteristics of specimens were measured using three standard tests. The machine is employed as a universal testing machine with a maximum capacity of 1,000 kN. The test setup for compressive strength, indirect tensile strength, and flexural strength, according to ASTM C496-96, ASTM C109/C109M-16, and ASTM C78/ /C78M-22 (ASTM International [ASTM], 1996; 2016; 2022), was shown in Figures 3, 4, and 5, respectively.

FIGURE 3. Compressive strength test

FIGURE 4. Indirect tensile strength test

FIGURE 5. Flexural strength test

Results and discussion

Compressive strength

The results showed that employing hybrid fiber with the addition of admixtures such as silica fume and superplasticizer increased concrete's compressive strength. The efficiency of additives in improving strength increased at early curing ages, as seen in Figure 6. When compared to control specimens, the average 28- and 180-day compressive strength of hybrid fiber concrete improved by 15.7 and 9.2%, respectively. This improvement is clearly when concrete is cured in clean water.

Compressive strength can also be illustrated in Figure 6, slightly improved after 360 days compared to 180 days' specimens' results.

According to the compressive test results obtained in this study, using hybrid fiber has a significant effect on compressive strength, which is likely due to an increase in mechanical bond strength when the fibers allow the formation of micro-cracks to be delayed and their propagation to be stopped to some extent. The effect of air, chloride, and sulphate

Elhawary, E. I. N., Elsafoury, A. H., Ahmad, S. S. E. (2022). Durability of hybrid fiber reinforced concrete at various environmental media. *Sci. Rev. Eng. Env. Sci.*, *31* (2), 88–100. DOI 10.22630/srees.2946

media on the compressive strength at 28, 180, and 360 days for control and hybrid fiber concrete were given, also, in Figure 6 as follows: Compressive strength for control specimens, in air media, at 28, 180 and 360 days were decreased from 72.84 to 72.30, from 78.75 to 78.13, and from 80.65 to 79.75 MPa, respectively, as compared to water media. Compressive strength for control specimens, in chloride media, at 28, 180, and 360 days was decreased from 72.84 to 70.90, from 78.75 to 76.50, and from 80.65 to 77.25 MPa, respectively, as compared to water media.

The need for concrete replacement will be evaluated by a series of tests, including a water absorption test, a density test, and a compression strength test.

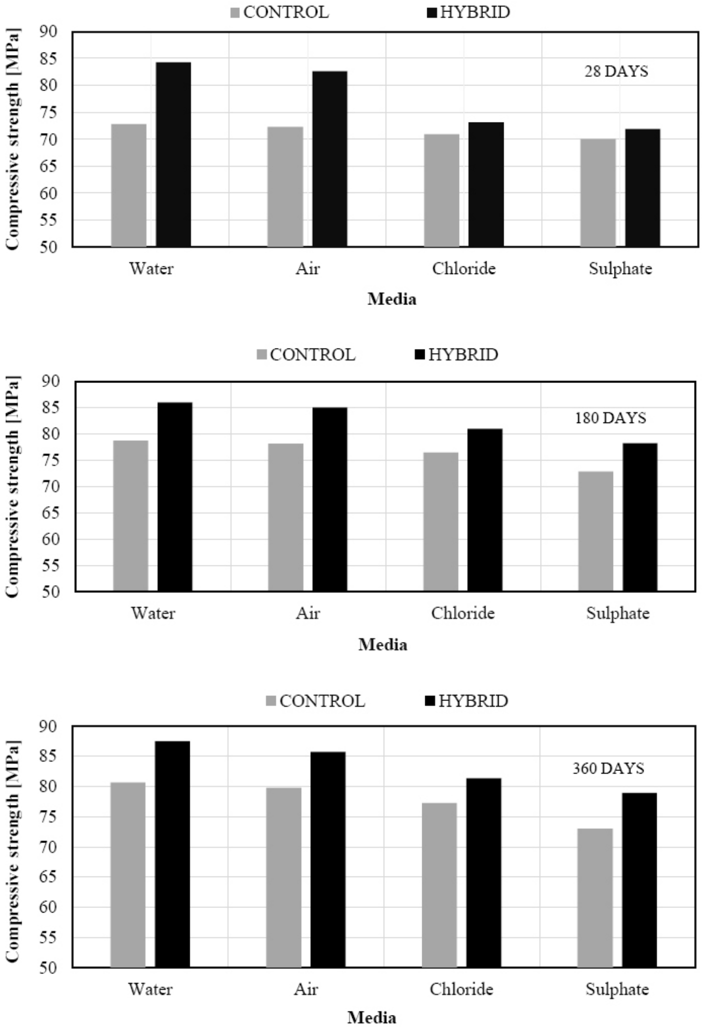

FIGURE 6. Compressive strength against curing media at different curing times for control and hybrid fiber reinforced concrete specimens

Compressive strength for control specimens, in sulphate media, at 28, 180 and 360 days were decreased from 72.84 to 70.05, from 78.75 to 72.83, and from 80.65 to 73 MPa, respectively, as compared to water media. These results clearly show there is little effect on compressive strength in air media and a severe effect on compressive strength in sulphate media.

Compressive strength for hybrid concrete specimens, in air media, at 28, 180 and 360 days were decreased from 84.3 to 82.63, from 86 to 85.03, and from 87.5 to 85.7 MPa, respectively, as compared to water media. Compressive strength for hybrid concrete specimens, in chloride media, at 28, 180 and 360 days were decreased from 84.3 to 73.13, from 86 to 80.97, and from 87.5 to 81.3 MPa, respectively, as compared to water media.

Compressive strength for hybrid concrete specimens in sulphate media at 28, 180 and 360 days decreased from 84.3 to 71.91, from 86 to 78.25, and from 87.5 to 78.9 MPa, respectively, as compared to water media. These results clearly show there is little effect on compressive strength in air media and a severe effect on compressive strength in sulphate media. On the other hand, the hybrid fiber concrete was more affected by aggressive media than the control specimen.

Flexural strength

The flexural strengths for hybrid fiber reinforced concrete containing steel and polypropylene fiber increased by 52.2, 13.9, and 17.4%, respectively, after 28, 180, and 360 days with respect to control specimens. This improvement is has occurred when concrete is cured in water media, as shown in Figure 7. From the obtained results in this research, increasing flexural strength is likely related to improvements in concrete's toughness matrix, compactness, and fiber distribution homogeneity. This result is in agreement with the results of Blunt and Ostertag (2009) where they found that hybridization led to an increased flexural strength of up to 196% relative to the control specimens.

It can be seen in Figure 7 that the effect of air, chloride, and sulphate media on the flexural for control and hybrid fiber concrete. Flexural strength in air media, at 28, 180, and 360 days decreased from 6.15 to 5.88, from 8.72 to 7.68, and from 15.50 to 13.00 MPa, respectively, as compared to water media. Flexural strength for control specimens, in chloride media, at 28, 180, and 360 days decreased from 6.15 to 5.25, from 8.72 to 6.02, and from 15.50 to 11.00 MPa, respectively, as compared to water media. Flexural strength for control specimens, in sulphate media, at 28, 180, and 360 days were decreased from 6.15 to 5.14, from 8.72 to 6.24, and from 15.50 to 10.50 MPa, respectively, as compared to water media. These results clearly show there is little effect on flexural strength in air media and a severe effect on flexural strength in sulphate media. Flexural strength for hybrid concrete specimens, in air media, at 28, 180, and 360 days were decreased from 9.36 to 9.07, from 9.93 to 9.75, and from 18.20 to 16.40 MPa, respectively, as compared to water media. Flexural strength for hybrid concrete specimens, in chloride media, at 28, 180, and 360 days decreased from 9.36 to 8.57, from 9.93 to 8.80, and from 18.20 to 14.50 MPa, respectively, as compared to water media. Flexural strength for hybrid concrete specimens, in sulphate media, at 28, 180, and 360 days decreased from 9.36 to 7.86, from 9.93 to 8.42, and from 18.20 to 13.00 MPa, respectively, as compared to water media. These results clearly show

Elhawary, E. I. N., Elsafoury, A. H., Ahmad, S. S. E. (2022). Durability of hybrid fiber reinforced concrete at various environmental media. *Sci. Rev. Eng. Env. Sci.*, *31* (2), 88–100. DOI 10.22630/srees.2946

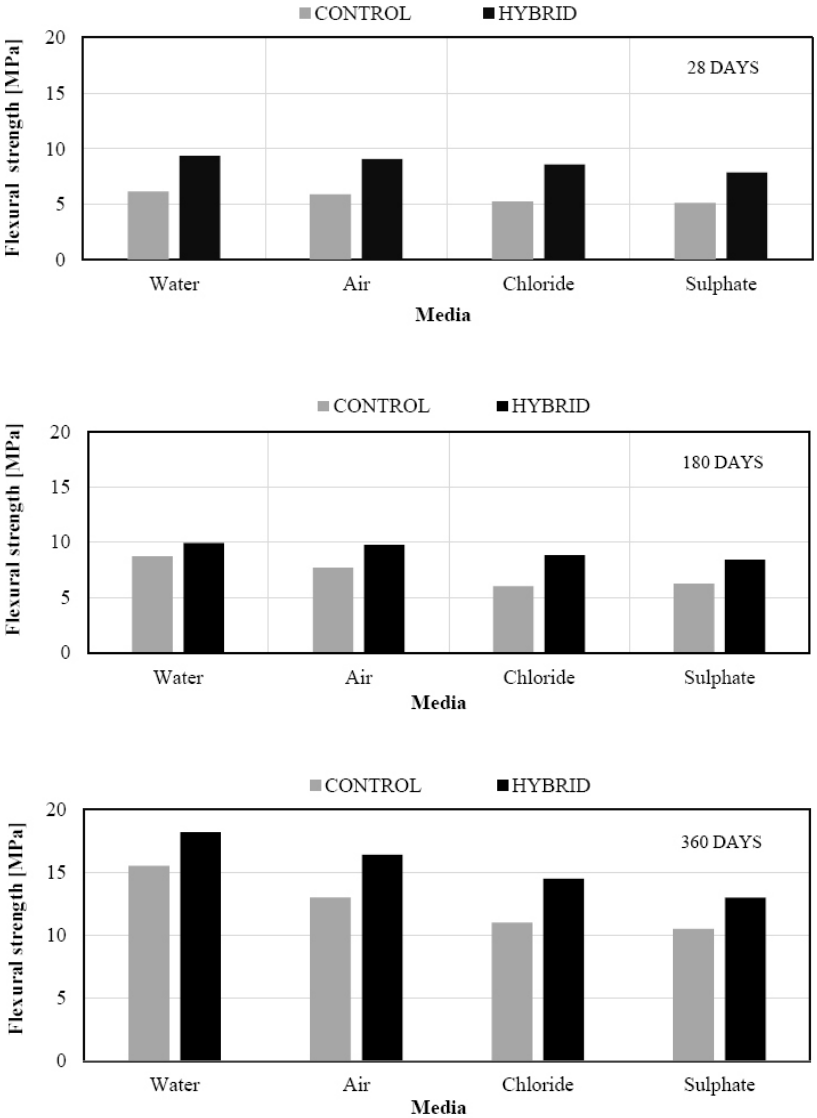

FIGURE 7. Flexural strength against curing media at different curing times for control and hybrid fiber reinforced concrete specimens

there is a little effect on flexural strength in air media and a severe effect on flexural strength in sulphate media. On the other hand, the hybrid fiber concrete was more affected by aggressive media than the control specimen.

Indirect tensile strength

The hybrid fiber reinforced concrete has a great influence on indirect tensile strength as shown in Figure 8. For different media, indirect tensile strength increased over time, up to 360 days. The indirect tensile strength for hybrid fiber reinforced concrete has reached the maximum value of 16.5, 16.8, 15.2, and 14.8 MPa compared to control specimens for water, air, chloride, and sulphate, respectively, after 360 days.

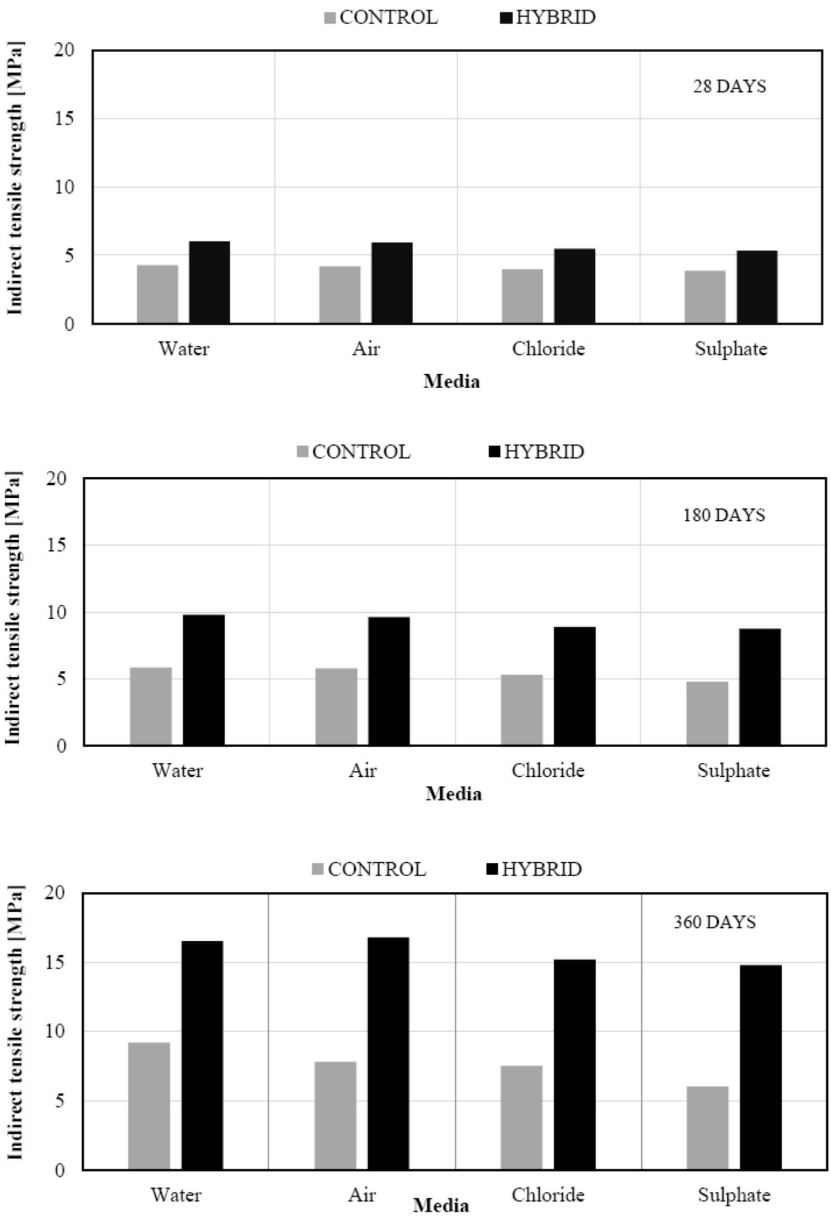

FIGURE 8. Indirect tensile strength against curing media at different curing times for control and hybrid fiber reinforced concrete specimens

From the results, using hybrid fiber reinforced concrete led to improve indirect tensile strength over time due to bonding between concrete and fiber, which made it withstand the toughest environmental conditions.

The effect of air, chloride, and sulphate media on the indirect tensile strength at 28, 180, and 360 days for control and hybrid fiber concrete was given, also, in Figure 8 as follows. Indirect tensile strength for control specimens, in air media, at 28, 180 and 360 days were decreased from 4.27 to 4.19, from 5.85 to 5.75, and from 9.20 to 7.80 MPa, respectively as compared to water media. Indirect tensile strength for control specimens, in chloride media, at 28, 180 and 360 days decreased from 4.27 to 3.95, from 5.85 to 5.28, and from 9.20 to 7.50 MPa, respectively, as compared to water media. Indirect tensile strength for control specimens, in sulphate media, at 28, 180 and 360 days decreased from 4.27 to 3.85, from 5.85 to 4.78, and from 9.20 to 6.00 MPa, respectively, as compared to water media.

These results clearly show there is little effect on indirect tensile strength in air media and a severe effect on indirect tensile strength in sulphate media. Indirect tensile strength for hybrid concrete specimens, in air media, at 28, 180 and 360 days decreased from 5.99 to 5.92, from 9.79 to 9.62, and from 16.50 to 16.40 MPa, respectively, as compared to water media. Indirect tensile strength for hybrid concrete specimens, in chloride media, at 28, 180 and 360 days decreased from 5.99 to 5.46, from 9.79 to 8.87, and from 16.50 to 15.20 MPa, respectively, as compared to water media. Indirect tensile strength for hybrid concrete specimens, in sulphate media at 28,180 and 360 days decreased from 5.99 to 5.32, from 9.79 to 8.74, and from 16.50 to 14.80 MPa, respectively, as compared to water media. These results clearly show there is little effect on indirect tensile strength in air media and a severe effect on indirect tensile strength in sulphate media. On the other hand, the hybrid fiber concrete was more affected by aggressive media than the control specimen.

Conclusions

The following are the results of an experimental investigation on hybrid fiber reinforced concrete:

- Using hybrid fiber reinforced concrete improves compressive strength up to 360 days.
- After 360 days in water media, the maximum indirect tensile strength of hybrid fiber reinforced concrete increased by 79.3% compared to control specimens.
- The flexural strengths of hybrid fiber reinforced concrete improved at water media by 17.4% after 360 days.
- Water is the best media and gives maximum strength up to 360 days.
- Sulphate media is the most aggressive media for hybrid fiber reinforced concrete.

References

ASTM International [ASTM] (1996). *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens* (ASTM C496-96). West Conshohocken, PA: ASTM International.

ASTM International [ASTM] (2016). *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)* (ASTM C109/ /C109M-16). West Conshohocken, PA: ASTM International.

ASTM International [ASTM] (2022). *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)* (ASTM C78/C78M-22). West Conshohocken, PA: ASTM International.

Atiş, C. D. & Karahan, O. (2009). Properties of steel fiber reinforced fly ash concrete. *Construction and Building Materials*, *23* (1), 392–399.

Banthia, N., Majdzadeh, F., Wu, J. & Bindiganavile, V. (2014). Fiber synergy in Hybrid Fiber Reinforced Concrete (HyFRC) in flexure and direct shear. *Cement and Concrete Composites*, *48*, 91–97.

Bencardino, F., Rizzuti, L., Spadea, G. & Swamy, R. N. (2008). Stress-strain behavior of steel fiber-reinforced concrete in compression. *Journal of Materials in Civil Engineering*, *20* (3), 255–263.

Blunt, J. D. & Ostertag, C. P. (2009). Deflection hardening and workability of hybrid fiber composites. *ACI Materials Journal*, *106* (3), 265–272.

Cattaneo, S. & Biolzi, L. (2010). Assessment of thermal damage in hybrid fiber-reinforced concrete. *Journal of Materials in Civil Engineering*, *22* (9), 836–845.

Cwirzen, A., Sztermen, P. & Habermehl-Cwirzen, K. (2014). Effect of Baltic seawater and binder type on frost durability of concrete. *Journal of Materials in Civil Engineering*, *26* (2), 283–287.

Dawood, E. T. & Ramli, M. (2011). High strength characteristics of cement mortar reinforced with hybrid fibers. *Construction and Building Materials*, *25* (5), 2240–2247.

Demirel, B., Gultekin, E. & Alyamaç, K. E. (2019). Performance of structural lightweight concrete containing metakaolin after elevated temperature. *KSCE Journal of Civil Engineering*, *23* (7), 2997–3004.

Egyptian Organization for Standardization and Quality Control [EOS] (2013). Cement. Part 1: Composition, specifications and conformity criteria for common cements (ESS 4756-1). Cairo: Egyptian Organization for Standardization and Quality Control.

Housing and Building National Research Center [HBNC] (2020). Egyptian code for design and construction of reinforced concrete structures (ECP 203). Cairo: Housing and Building National Research Center.

Khitab, A., Arshad, M. T., Hussain, N., Tariq, K., Ali, S. A., Kazmi, S. M. S. & Munir, M. J. (2013). Concrete reinforced with 0.1 vol% of different synthetic fibers. *Life Science Journal*, *10* (12), 934–939.

Kim, Y. J., Hossain, M. & Zhang, J. (2013). A probabilistic investigation into deterioration of CFRP – concrete interface in aggressive environments. *Construction and Building Materials*, *41*, 49–59.

Mohammadi, Y., Singh, S. P. & Kaushik, S. K. (2008). Properties of steel fibrous concrete containing mixed fibres in fresh and hardened state. *Construction and Building Materials*, *22* (5), 956–965.

Muigai, R., Moyo, P. & Alexander, M. (2012). Durability design of reinforced concrete structures: a comparison of the use of durability indexes in the deemed-to-satisfy approach and the full-probabilistic approach. *Materials and Structures*, *45* (8), 1233–1244.

Najaf, E., Orouji, M. & Zahrai, S. M. (2022). Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber. *Nonlinear Engineering*, *11* (1), 58–70.

Noushini, A., Samali, B. & Vessalas, K. (2013). Effect of polyvinyl alcohol (PVA) fiber on dynamic and material properties of fiber reinforced concrete. *Construction and Building Materials*, *49*, 374–383.

Orouji, M., Zahrai, S. M. & Najaf, E. (2021). Effect of glass powder & polypropylene fibers on compressive and flexural strengths, toughness and ductility of concrete: an environmental approach. *Structures*, *33*, 4616–4628.

Qian, C. X. & Stroeven, P. (2000a). Development of hybrid polypropylene-steel fiber-reinforced concrete. *Cement and Concrete Research*, *30* (1), 63–69.

Qian, C. & Stroeven, P. (2000b). Fracture properties of concrete reinforced with steel–polypropylene hybrid fibers. *Cement and Concrete Composites*, *22* (5), 343–351.

Elhawary, E. I. N., Elsafoury, A. H., Ahmad, S. S. E. (2022). Durability of hybrid fiber reinforced concrete at various environmental media. *Sci. Rev. Eng. Env. Sci.*, *31* (2), 88–100. DOI 10.22630/srees.2946

Sivakumar, A. & Santhanam, M. (2007). Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibers. *Cement and Concrete Composites*, *29* (8), 603–608.

Val, D. V. & Stewart, M. G. (2003). Life-cycle cost analysis of reinforced concrete structures in marine environments. *Structural Safety*, *25* (4), 343–362.

Yang, K. H. (2011). Tests on concrete reinforced with hybrid or monolithic steel and polyvinyl alcohol fibers. *ACI Materials Journal*, *108* (6), 664–672.

Yao, W., Li, J. & Wu, K. (2003). Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction. *Cement and Concrete Research*, *33* (1), 27–30.

Yu, R., Spiesz, P. & Brouwers, H. J. H. (2014). Static properties and impact resistance of a green Ultra-High Performance Hybrid Fiber Reinforced Concrete (UHPHFRC): Experiments and modeling. *Construction and Building Materials*, *68*, 158–171.

Summary

Durability of hybrid fiber reinforced concrete at various environmental media. Fiber's addition to concrete mixture attracts researchers to determine the effect of fiber type on durability properties of hybrid performance concrete. In the present work, steel and polypropylene fibers are used in hybrid form in the experimental program. The objective of this paper is to investigate the mechanical properties of hybrid fiber reinforced concrete subjected to four various media: air, water, sodium chloride, and magnesium sulphate with a 7% concentration. The results showed that using hybrid fibers which consist of 1% steel fiber and 0.3% polypropylene fiber improved the compressive strength, splitting tensile strength, and flexural strength for different media for up to 360 days.