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Strength of Different Fiber Reinforced Concrete in Marine Environment

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In this paper, the compressive strength, tensile strength and growing rate of compressive strength in 3, 7, 28 and 90 day ages for steel, polypropylene and hybrid steel-polypropylene fiber reinforced concrete with different water to binder ratios (0.4 and 0.5) in a real marine condition and tidal zone were determined. Moreover, regarding a large number of gathered data from the other researches, new equations between compressive strength, tensile strength and elasticity modulus for different types of steel fiber reinforced concrete were proposed. Finally, proposed equations were compared and verified for a marine environment. Based on marine environment results, compressive strength of polypropylene and hybrid steel-polypropylene fiber reinforced concrete were about 18 % and 5 % greater than plain concrete in 90 day ages, respectively and steel fibers had not meaningful effect on compressive strength in 90 day ages. By increasing the water to binder ratio, the compressive strength of plain concrete and steel fiber reinforced concrete was decreased about 18 % and 25 %, respectively. Also in 28 and 90 days, steel fiber reinforced concrete tensile strength was increased about 15 % in 0.4 water to binder ratio and 20 % in 0.5 water to binder ratio rather than plain concrete. Effect of steel fiber in increment of plain concrete tensile strength in 0.5 water to binder ratio was higher than 0.4. Steel fiber reinforced concrete elasticity modulus was lower than related plain concrete and with increasing the compressive strength, the difference between elasticity modulus of steel fiber reinforced concrete and plain concrete was decreased.

Keywords: steel fiber, polypropylene fiber, compressive and tensile strengths, elasticity modulus.

1. INTRODUCTION

Concrete is the most widely used structures material because of so many properties such as low expenses, general accessibility and its ability to get cast in any figure and formation, thus it has vast usage in different construction materials [1 – 2]. However, use of admixtures and fibers together in concrete led to increase of toughness, flexural capacity and other strength parameter as well as reduction of brittleness [3]. There are different fibers which are used in cement-based materials such as polypropylene, carbon, steel and glass [2].

Qian and Stroeven [4] studied the application of mono and Hybrid Polypropylene-Steel Reinforced Concrete (P+S) Fiber Reinforced Concrete (FRC). They used Polypropylene Fiber (PF) with a constant length and diameter and different volume fraction (v_f) and steel fibers with different types, lengths and v_f. They found that by decreasing length of the used fiber, compressive strength of concrete (f_c) was increased. Qing et al. [5] investigated the mechanical properties of layered Steel and Polypropylene Fiber Reinforced Concrete ((S+P) FRC). They concluded that $f_{c(PFRC)}$ slightly decreased while the f_c of Layered Hybrid Fiber Reinforced Concrete (LHFRC) increased slowly in comparison with Plain Concrete (PC) samples. The tensile strength of concrete (f_t) of concrete increased by 8.6 % for Polypropylene Fiber Reinforced Concrete (PFRC) and 11.2 % for LHFRC. The flexural strength (f_f) increased by 23.4 % for LHFRC and 4.2 % for PFRC. The index of flexural toughness of LHFRC was 7.8 times more than PC and this parameter for PFRC was 4.1 times greater than PC. Gao et al. [6] studied durability of (P+S) FRC and their frost resistant in bridge deck pavement. They found that effect of adding Hybrid Polypropylene-Steel Fiber (HPSF) on f_c is not remarkable. The f_f was enhanced about 25 % by adding PSF to the PC. Pliya et al. [7] investigated on contribution of PF and steel fibers in improving the behavior of high strength concrete subjected to high temperature. The residual mechanical properties containing f_c and porosity and the mass loss were analyzed on four groups of high strength concrete: Plain High Strength Concrete (PHSC), Polypropylene Fiber Reinforced High Strength Concrete (PFRHSC), Steel Fiber Reinforced High Strength Concrete (SFRHSC) and Polypropylene and Steel Fiber Reinforced High Strength Concrete ((P+S) FRHSC). Based on their results, for all groups of concretes, by increasing the temperature, residual f_c decreased. Compared with PHSC, a reduction and increment of relative compressive residual strength (f_{cr}) was observed in PFRHSC and SFRHSC, respectively. This parameter for (P+S) FRHSC were lower than SFRHSC and higher than PHSC. Alavi Nia et al. [8] studied the effect of using steel fibers and PF into the PHSC on the impact resistance in FRC. They found that by adding fibers to concrete, f_c and f_t increased regardless of the water to binder ratio (*w/b*). Adding 1 % steel fibers caused f_t of concrete with *w/b* of 0.46 and 0.36 were increased about 62 % and 30 %, respectively. Whereas, compared to the reference specimen, f_c was increased 14 % and 8 % in

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specimens with 1 % steel fibers and *w/b* of 0.46 and 0.36, respectively. However, the results showed that increasing steel fibers leads to increase on the concrete f_t more than PF. Aslani and Nejadi [9] investigated on f_c, f_t and elastic modulus of concrete (E_c) of Self-Compacting Concrete (SCC) incorporating steel fibers and PF. They concluded that the f_c of the Polypropylene and Steel Fiber Reinforced Self-Compacting Concrete (PSFR-SCC) mix at 91 days was 11 %, 8 %, and 1 % higher than the Plain Self-Compacting Concrete (P-SCC), Polypropylene Fiber Reinforced Self-Compacting Concrete (PFR-SCC), and Steel Fiber Reinforced Self-Compacting Concrete (SFR-SCC) mixes, respectively. Also the results showed that the f_t of the SFR-SCC mix at 91 days is 19 %, 16 %, and 12 % higher than that of the PFR-SCC, P-SCC, and PSFR-SCC mixes, respectively. The E_c of the PSFR-SCC mix at 91 days is 1 %, 1 %, and 0.8 % higher than that of the PFR-SCC, SFR-SCC, and P-SCC mixes, respectively. They concluded that f_f of SFR-SCC mix at 91 days is 6 %, 1 %, and 0.2 % higher than that of the PFR-SCC, P-SCC, and PSFR-SCC mixes, respectively. Chi et al. [10] studied the unified failure envelope for HFRC subjected to true triaxial compression. In this research corrugated steel fibers was used at different v_f and aspect ratios. The true triaxial test performed on different concrete mixtures with various steel fibers, PF and aspect ratios and v_f and (P+S) F. They investigated that as the v_f of steel fibers reaches 1.5 %, there was an approximately linear relationship between Steel Fiber Reinforced Concrete (SFRC) axial strength and the v_f. For PFRC, the concrete strength under true triaxial compression with addition of PF up to about 10 % was increased. In all of the loading cases, with increasing the v_f of steel fibers, the strength of (P+S) FRC gradually increased. With increasing v_f of PF, the strength of (P+S) FRC fluctuated. Also a decrease in (P+S) FRC strength was also observed where steel fibers high aspect ratio and v_f was combined with high v_f of PF. Ganesan et al. [11, 12] performed two researches on bond stress slip response of bars embedded in Hybrid Fiber Reinforced High Performance Concrete (HFRHPC) and behavior of HFRC beam–column joints under reverse cyclic loads. v_f of steel fibers was 0.5 % and 1.0 % and this parameter for PF was 0.1 %, 0.15 % and 0.2 %. They found that by addition of steel fibers or PF to high performance concrete the bond strength was no important for smaller diameter bars. HFRHPC mixtures, with a combination of 1 % steel fibers and 0.1 % PF, significantly enhanced the bond stress for 12 mm, 16 mm and 20 mm diameter bars by about 50 %, 46 % and 33 % respectively. Also the anchorage length requirement of deformed bars can be reduced by the usage of HFRHPC. In HFRHPC specimen with 1 % steel fibers and 0.15 % PF energy absorption capacity and displacement ductility index increased by 3.6 times and 3.1 times respectively when compared to HPC. Also they showed that in the beam–column joints it is possible to decrease the congestion of steel reinforcement by using HFRHPC and this reduces the construction difficulties. Rashiddadash et al. [13] investigated about flexural toughness of HFRC containing metakaolin and pumice. They used v_f of steel fibers equal to 0.5 %, 0.75 and 1 % and v_f of PF equal to 0.25 %, 0.5 % and 0.75 %. They concluded that the highest f_f is related to mixture with higher steel fibers percentages v_{fpp}= 0 %. Furthermore, HFRC toughness and energy absorption with higher steel fibers content were relatively higher than those containing less steel fibers. PF had no effect on toughness index. Also adding pozzolan had no effect on load-deflection relationship and mainly was related on the steel fibers and PF percentage. Afroughsabet et al. [1] studied the mechanical and durability properties of high-strength concrete containing steel fibers and PF. They showed that f_c increased from 5 – 15 % and 7 – 19 % as a result of addition of PF and steel fibers to the mix, respectively. Thus the effect of steel fibers on f_c was more important than PF. (P+S) FRC strength were up to 18 % greater than PC. With substitution of a portion of steel fibers with PF the f_c was decreased. (P+S) FRC containing 0.15 % PF and 0.85 % steel fibers had highest f_c. Their results also indicated that an increase in the f_t ranging from 13 – 58 % and 11 – 20 % were attained, through the addition of steel fibers and PF to the mix, respectively. The $f_{t[(P+S)FRC]}$ improvement ranged from 23 – 52 % rather than simple mixtures. An increase in the $f_{f(PFRC)}$ and $f_{f(SFRC)}$ rather than $f_{c(PC)}$ varied from were 5 – 13 % and 9 – 61 %. An increase PF content led to important reductions in f_f of hybrid mixes. Addition of PF causes a slight reduction in the concrete electrical resistivity. Whereas, addition of steel fibers significantly decreases these parameters. (S+P) FRC had contradictory behavior in electrical resistivity. Mixture includes 0.45 % PF reached the lowest water absorption (0.72 %) among all PFRC. The lowest water absorption (0.69 %) was related to mix with 1.0 % steel fibers. Among all FRC, the mixture with 0.3 % PF and 0.7 % steel fibers has been found to exhibit the lowest water absorption (0.62) rather than PC. Huang et al. [14] studied about seismic performance of (S+P) FRC columns. Based on their results, columns with (P+S) FRC did not show a better treatment than SFRC in this aspect. In (P+S) FRC columns the spalling of concrete cover could be delayed and importantly reduced compared with RC columns. Jameran et al. [15] investigated the mechanical properties of (P+S) FRC under elevated temperature. They concluded there was very little difference for $f_{c(PFRC)}$, $f_{c(SFRC)}$ and $f_{c[(S+P)FRC]}$. Increment of steel fibers portion in mixtures led to much lower decrease of f_f. Increment of PF portion in mixtures led to much lower reduction in f_t. Caggiano et al. [16] studied the post-cracking response in (P+S) FRC. They found that use of (P+S) FRC is a desirable solution for improvement the cement-based matrices post-cracking treatment both in compression and in bending. (P+S) FRC mixtures containing more steel fibers indicated the greater post-cracking bending strengths. Change of PF portion in (P+S) FRC had no significant effect on toughness. Sermet and Ozdemir [17] investigated the punching behavior of SFRC and PFRC slabs under normal load. Based on their results, the punching capacity and displacement of PC was increased 21.43 and 12.43 %, respectively by adding steel fibers to it. However, the punching capacity and displacement enhancement value for PFRC were showed 15.28 and 20.14 % respectively compared to the control specimen. The displacement of the concrete containing PF was greater than mixture having steel fibers. Serrano et al. [18] studied the fire resistance of concrete with PF or steel fibers. Results showed that SFRC was subjected to direct heat action and had higher temperatures than PC. Concrete with PF, because of its higher permeability at fire, reached lower temperatures than PC. Also SFRC or PFRC was subjected to the direct heat action, cool more slowly than PC. $f_{c(PFRC)}$ or $f_{c(SFRC)}$ was greater than $f_{c(PC)}$, when subjected to thermal aggressions of 400 °C.

2. OVERVIEW OF CORRELATION BETWEEN PC AND SFRC MECHANICAL PROPERTIES

The assessment of f_c with time was major interest for structural engineers [19]. ACI and CEB-FIP standards proposed two equations for predicting fc in different concrete life times:

$$f_c(t) = \exp\left\{s\left[1-\left(\frac{28}{t}\right)^{0.5}\right]\right\}\mathrm{f}_{c28} \text{ [20]}; \quad (1)$$

$$\mathrm{f}_c(t) = \left(\frac{t}{a+bt}\right)\mathrm{f}_{c28} \text{ [21]}, \quad (2)$$

where *a* (in days) and *b* are constants which depend on curing condition and cement type; *S* coefficient depends on cement type; $f_c(t)$ and f_{c28} are f_c at *t* and 28 days in MPa, respectively.

In design of different concrete structures, f_t is more significant than f_c. Commonly f_c, *w/b* and concrete age can be effected on f_t. Because of easier cracks propagation in concrete in tensile loads, f_t of concrete is much lower than the f_c [22]. Some of the developed relationships between f_t and f_c are:

$$f_t = 1.56\left(\frac{f_c-8}{10}\right)^{\frac{2}{3}} \text{ [20]}; \quad (3)$$

$$f_t = 1 + 0.05 f_c \text{ [23]}; \quad (4)$$

$$f_t = 0.185 - (f_c)^{0.735} \text{ [24]}; \quad (5)$$

$$f_t = [0.20 - 0.88](f_c)^{[0.50-0.73]} \text{ [24, 25]}. \quad (6)$$

Elastic Modulus of Concrete (E_c) is an essential and basic parameter that needs to be determined to design plain, reinforced and pre-stressed concrete structures. E_c can be determined by theoretical and experimental approaches. Theoretical models are complex for an analyzing, because of the E_c is a function of several parameters related to multi-phase [26]. Engineers and researchers have tried to investigate some shortcuts to predict E_c by applying theoretical and empirical methods. E_c is usually represent as a function of *fc* [27]. Some of these equations for PC:

$$\mathrm{E}_c = 21500\alpha\left(\frac{f_c}{10}\right)^{\frac{1}{3}} \text{ [20]}; \quad (7)$$

$$\mathrm{E}_c = 0.043 K_1 \lambda^{1.5}(f_c)^{0.5} \text{ [20, 23]}; \quad (8)$$

$$\mathrm{E}_c = 3.25(f_c)^{0.5} + 14 \text{ [20]}; \quad (9)$$

$$\mathrm{E}_c = [4550-9500](f_c)^{[0.3-0.5]} \text{ [20, 28]}, \quad (10)$$

where α is the aggregate type factor; K_1 is the correction factor for source of aggregate, λ is equal about 2300 kg/m^3.

Choi and Yuan [29] proposed $f_{t(GFRC)} = 0.6(f_c)^{0.5}$ for Glass Fiber Reinforced Concrete (GFRC), and $f_{t(PFRC)} = 0.55(f_c)^{0.5}$ for Polypropylene Fiber Reinforced Concrete (PFRC). Many researchers have tried to extract relations between $f_{t(FRC)}$ and f_c.

$$(f_t)_{FRC} = \frac{f_c}{20-\sqrt{\vartheta_f l/d}} + 0.7 + \sqrt{\vartheta_f\, l/d} \text{ [30]}; \quad (11)$$

$$(f_t)_{FRC} = \left[0.63 + 0.46\,\vartheta_f\, l/d\right]\sqrt{f_c} \text{ [31]}; \quad [12]$$

$$(f_t)_{FRC} = [0.12 - 0.57](f_c)^{[0.50-0.96]} \text{ [25, 32–34]}; \quad [13]$$

$$(f_t)_{FRC} = \left[0.614 + 0.4(\vartheta_f\, l/d)^{1.029}\right]\sqrt{f_c} \text{ [35]}; \quad [14]$$

$$(f_t)_{FRC} = 0.144(f_c)^{0.941}(Age)^{-0.153}\left(\vartheta_f\, l/d\right)^{0.002}\left(\frac{w}{b}\right)^{-0.215} \text{ [24]}; \quad [15]$$

$$(f_t)_{FRC} = 0.474(f_c)^{0.527}(Age)^{0.014}\left(\vartheta_f\, l/d\right)^{0.011}\left(\frac{w}{b}\right)^{-0.163} \text{ [24]}; \quad [16]$$

$$(f_t)_{FRC} = \left[0.0715 + 0.067(0.645\vartheta_f\, l/d)^{\frac{f_c}{107}}\right] f_c \text{ [36]}. \quad [17]$$

Finally, proposed equations were compared and verified for a marine environment.

3. EXPERIMENTAL DETAILS

Ordinary Portland Cement (OPC) Type II was used in the present study. The chemical compositions of cement and silica fume are shown in Table 1. As can be known, substitution a portion of the cement by pozzolanic materials such as silica fume could be used to improve the mechanical properties of concrete and reduced porosity and consolidate the transition zone between fibers and the cement paste. The durability of concrete, especially in marine conditions, could be improved by silica fume [13, 48]. Chabahar limestone rubble as a coarse aggregate with a maximum size of 19 mm and fine aggregate with a 2.6 fineness modulus were used. The specific gravity of the coarse and fine aggregates was 2.65 and 2.56, respectively. Mineralogical composition of fine and coarse aggregates is shown in Table 1. Naphthalene-based super-plasticizer with the commercial name of ADMIX PR230 was used to improve workability.

The geometry and mechanical properties of fibers are provided in Table 2 and concrete mix proportions are also provided in Table 3. The fresh concrete was cast in 150 × 300 mm cylinder specimens with *w/b* = 0.4 and 0.5. The experiments were carried out at 3, 7, 28, and 90 days of curing age and silica fume as a cement replacement was added by 10 % of weight to cementitious materials. In all tests, three specimens were tested for each curing age. Specimens were cast in steel molds and were compacted by vibration table.

Table 1. Composition of Portland cement, silica fume and aggregates

Chemical composition, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I	$K_2O + Na_2O$ (eq)	others
Portland cement	21.8	4.2	4.6	61.9	3.4	1.8	0.8	0.9	0.6
Silica fume	92.1	0.6	0.9	0.6	0.9	0.1	1.6	1.6	1.6
Gravel	7.9	0.6	1.1	44.1	4.6	0.1	40.9	0.4	0.3
Sand	51.9	5.8	7.6	16.1	7.8	0	8.1	2.1	0.6

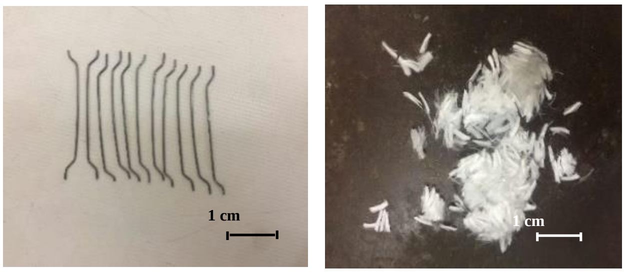
Table 2. Properties of hooked-end steel fibers and PF

Fiber type	Fiber shape	Length, mm	Diameter, mm	Aspect ratio	Density, kg/m^3	Tensile strength, N/mm^2
Steel	Hooked-end	50	0.80	63	7.80	1050
PP	Straight	12	0.022	545	0.91	350

Table 3. Concrete mixtures

Mixture index	Water	Cement	Silica Fume	Fine agg.	Coarse agg.	Fiber v_f, %		SP, %
	kg/m^3					Steel fiber	PF	
PC (w/b = 0.4)	160	360	40	758	1088	–	–	1.0
SFRC (w/b = 0.4)	160	360	40	824	996	0.5	–	1.2
PFRC (w/b = 0.4)	160	360	40	824	996	–	0.5	1.3
(S+P) FRC (w/b = 0.4)	160	360	40	824	996	0.25	0.25	1.3
PC (w/b = 0.5)	200	360	40	758	1088	–	–	–
SFRC (w/b = 0.5)	200	360	40	824	996	0.5	–	–

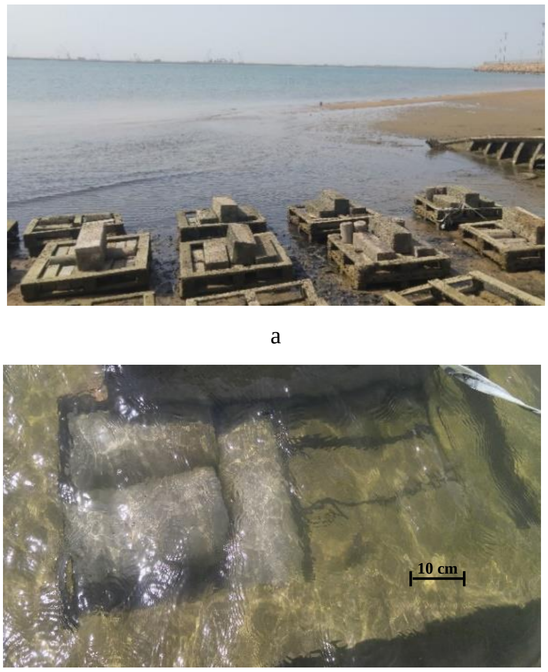
The fibers are shown in Fig. 1.



a b

Fig. 1. Used fiber type: a – steel; b – PP

After completing the initial condition of curing in the first days, all specimens transferred and placed in the tidal zone condition of Oman Sea until their testing ages. Fig. 2 shows the mentioned environment and some of concrete samples for the f_c and f_t tests.



a

b

Fig. 2. Specimens in Oman marine environment: a – marine environment; b – concrete samples

4. RESULTS AND DISCUSSION

4.1. Compressive strength

To show the effect of using different fiber types on the compressive strength, tests were performed in two different w/b equal to 0.4 (as a concrete with low porosity) and 0.5 (as a concrete with high porosity). Results of this part of experiments are shown in Fig. 3. Previous studies showed that, usually, using steel fiber with different shapes and v_f, has not considerable effect on the f_c in a standard laboratory condition and $f_{c(PFRC)}$ has (5 – 20) % higher $f_{c(PC)}$ [1, 3, 16].

In the marine environmental condition, approximately same results were concluded, too. The best improvement of f_c was related to $f_{c(PFRC)}$ (w/b = 0.4).

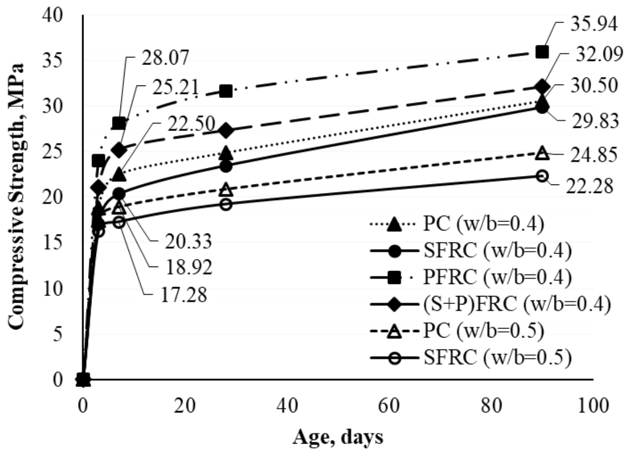


Fig. 3. Comparison of f_c for $f_{c(PC)}$, $f_{c(SFRC)}$, $f_{c(PFRC)}$ and $f_{c[(S+P)FRC]}$

According to Fig. 3, effect of adding PF to PC was more significant (from 28% in 3 days to 18% in 90 days) in the increment of the fc. Generally, using fiber had positive effect on concrete strength properties in comparison with PC which was in 90 days for PFRC and (S+P)F about 18% and 5%, respectively, and for SFRC had not meaningful effect in fc. The reason can be more flexibility of PF in comparison with SF. The increment of fc in PFRC rather than (S+P) FRC and SFRC can be explained by the more compatibility, capability to restrain the cracks extension, decrease of the stress concentration extension at the cracks edge, change the cracks direction and delay the cracks growing rate and presumably because the induction of more homogeneous behavior to concrete [29]. As can be seen from Fig. 3 and by definition of f_{c7}/f_{c90} ratio due to the uniform trend from 7 to 90 days, minimum and maximum of f_{c7}/f_{c90} were related to SFRC and (S+P) FRC (w/b = 0.4) with about 0.7 and 0.8, respectively. Also, by changing the w/b from 0.4 to 0.5 in 90 days' age, the $f_{c(PC)}$ and $f_{c(SFRC)}$ were decreased about 18 % and 25 %, respectively. The reason is higher content of water in mixture and more capillary cavities and porosity which by adding steel fibers, this porosity may be increased.

4.2. Tensile strength

In the marine structures, regarding the importance of weight in the stability of the constructed structures, the steel fiber was selected and tensile experiments were performed in comparison with PC. The results of $f_{t(PC)}$ and $f_{t(SFRC)}$ of cylinder specimens at 28 and 90 days with different w/b ratios are shown in Table 4.

As can be seen from Table 4, f_{t28} was increased about 15 % and 20 % with adding steel fibers to the PC in 0.4 and 0.5 w/b, respectively. f_{t90} was increased with addition of steel fibers to the PC approximately 16 % and 19 % in 0.4 and 0.5 w/b, respectively. Using fibers in the concrete increases f_t by improving weakness of transition zone and prevent the micro cracks extension [2].

Table 4. Results of f_t test

Mixture index	f_{t28}, MPa	f_{t90}, MPa
PC (w/b=0.4)	3.17	3.68
SFRC (w/b = 0.4)	3.64	4.27
PC (w/b = 0.5)	2.57	2.96
SFRC (w/b = 0.5)	3.08	3.52

Moreover, by adding fibers to the concrete, the bonding between concrete materials increases [37]. Another considerable factor on tensile strength is the porosity of concrete which by increasing w/b, the porosity increases [19]. Results showed that effect of steel fiber in increment of $f_{t(SFRC)}$ with w/b = 0.5 was more significant than SFRC with w/b = 0.4 in 90 days age.

4.3. Correlation between SFRC mechanical properties

To analyze the obtained results in the present work, correlation between SFRC tensile and compressive strengths, compressive strength growing rate and elasticity modulus through compressive strength were discussed.

4.3.1. Correlation between SFRC tensile and compressive strengths

Regarding the previous researches [2, 3, 9, 34, 39 – 42], a comparison was performed between present work in marine environment and other gathered data and issues (Fig. 4).

As can be seen from Fig. 4, Eq. 3 and Eq. 4 were presented beside the obtained data from previous researches on PC and SFRC and performed experimental results in marine environment. In laboratory condition and for f_c lower than the range of 20 – 40 MPa, $f_{t(SFRC)}$ and $f_{t(PC)}$ was approximately, same. Fibers role in increment of $f_{t(SFRC)}$ was started at range of 20 – 40 MPa for f_c about 1 – 19 % more than $f_{t(PC)}$. Mechanism of fiber reinforcement mainly consists of fiber bonding and pullout effects [25].

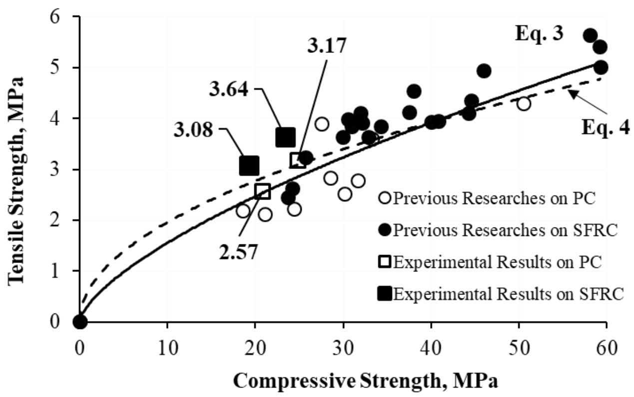


Fig. 4. Comparison between obtained data from previous researches and experimental results on $f_{t(PC)}$ and $f_{t(SFRC)}$

As a result, after cracking, fibers assist to loads carrying at the internal micro cracks and therefore, concrete with its inherent fragile matrix as well as low f_t and impact resistances will change into the ductile composite with superior f_t, higher crack resistance and special post-cracking treatment before failure [2]. According to Fig. 4 and obtained data from the previous researches, Eq. 17 can be proposed for SFRC with R^2 equal to 0.996:

$$f_{t(SFRC)} = 0.3\,(f_c)^{0.7}. \tag{17}$$

It should be noted that for the same amount of $f_{t(SFRC)}$, the values of f_t in marine environment was higher than laboratory conditions. In marine environment, due to inherent prone to corrode of steel fibers and vast surface area to volume ratio, steel fibers are efficiently screened by the lime rich layer and the rust of these fibers maybe increase of bonding and increase of f_t [43].

4.3.2. Compressive strength growing rate

By defining Eq. 18 for CSGR, a comparison was performed between the previous researches [1, 9, 29, 40] and present work in marine on CSGR of PC and SFRC (Table 9).

$$\text{CSGR}_{i\text{-}j}(\%) = [(f_{cj} - f_{ci})/f_{ci}]\times 100, \tag{18}$$

where subscribes of i and j refer to the compared ages of the concrete life time for calculating CSGR.

Table 5. $\text{CSGR}_{i\text{-}j}$ for PC and SFRC

Subject	Mixture index	$\text{CSGR}_{i\text{-}j}$, %	
		7 – 28	28 – 90
Previous researches	PC	21.6	12.6
	SFRC	31.2	18.6
Present work in marine environmental	PC (w/b = 0.4)	10.4	22.8
	SFRC (w/b = 0.4)	15.3	27.3
	PC (w/b = 0.5)	10.3	19.1
	SFRC (w/b = 0.5)	11.2	16.0

In Table 5, it should be noted that $\text{CSGR}_{i\text{-}j}$ in previous researches is average of values from various researches. According to Table 5, $\text{CSGR}_{7\text{-}28}$ of PC and SFRC from laboratory to marine conditions was decreased about 10 % (was same for both w/b) and 15% (for w/b = 0.4) and 20 % (for w/b = 0.5), respectively. Although, $\text{CSGR}_{28\text{-}90}$ of PC and SFRC from laboratory to marine conditions was increased

10 % (for w/b = 0.4) and 5 % (for w/b = 0.5) and 10 % (for w/b = 0.4), respectively. However, by adding the steel fiber to the PC in laboratory condition, $CSGR_{7\text{-}28}$ was increased 10 % which in marine environment $CSGR_{7\text{-}28}$ was increased 5 %. Moreover, by adding the steel fiber to the PC, $CSGR_{28\text{-}90}$ was increased about 5 % which was same for both environments. Regarding Table 5, in marine environment, the value of $CSGR_{7\text{-}28}$ and $CSGR_{28\text{-}90}$ for PC with w/b = 0.4 and 0.5 was approximately same. However, by increasing the w/b from 0.4 to 0.5, the $CSGR_{7\text{-}28}$ and $CSGR_{28\text{-}90}$ of SFRC was decreased about 4 % to 11 %. Therefore, the porosity increment effect in $CSGR_{7\text{-}28}$ and $CSGR_{28\text{-}90}$ of SFRC was more important than PC. By load applying, mainly stress concentration and related failure is started from major capillary cavities and cracks within hydrated cement matrix and commonly capillary spaces volume in this matrix are depended on mixture water content at the beginning of reaction and cement hydration degree [19]. Moreover, by adding the steel fiber to the PC the capillary spaces volume was more increased.

It seems that by increasing the capillary the process of hydration and complete the empty spaces are delayed.

4.3.3. Elasticity modulus through compressive strength

Commonly, some parameters which can have effect on $E_{c(PC)}$ are the aggregate type, stress level regarding the rate of loading and concrete moisture condition [46]. In case of SFRC, another factor is fiber properties such as strength properties, aspect ratio, shape factor and different v_f [47]. Moreover, by applying a constant force to the PC and SFRC, it was concluded that the strain of SFRC is higher than PC, because of the incremental role of steel fiber on deformation and controlling the crack.

Thus, for a constant f_c, SFRC with higher strain had lower E_c. It should be noted that the type of calculated elasticity modulus in the present study was secant modulus which is slope of a straight line between the coordinate system origin and a certain point of curve [45].

Fig. 5 shows a performed comparison between the $E_{c(SFRC)}$ and f_c of previous researches [3, 9, 20, 23, 38, 40, 44] and Eq. 7 and Eq. 8 for PC and SFRC at 28 days' age.

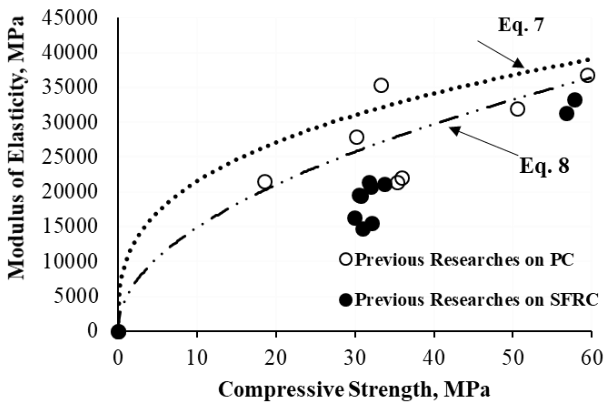


Fig. 5. Comparison between CEB-FIP 90 and ACI 318-11 proposed equations and obtained data from previous researches on $E_{c(PC)}$ and $E_{c(SFRC)}$ through f_c

As can be seen from Fig. 5, results of previous researches on $E_{c(SFRC)}$ were 2 – 30 % lower than Eq. 7 and Eq. 8. However, with increasing the f_c, the difference between $E_{c(SFRC)}$ and $E_{c(PC)}$ was decreased. Regarding the obtained data from the previous researches on SFRC, Eq. 19 can be proposed with R^2 = 0.957.

$$E_{c(SFRC)} = 565\, f_c. \tag{19}$$

According to Eq. 19, relation between $E_{c(SFRC)}$ and f_c, was approximately linear and obtained diagram from Eq. 19 because of higher strain rather than PC, will be situated below the diagram of Eq. 7 and Eq. 8.

5. CONCLUSIONS

Regarding the performed experiments and obtained data from the previous researches, the following results can be concluded.

Effect of adding PF to PC on f_c in marine environment (from 28 % in 3 days to 18 % in 90 days) was more significant than adding steel fiber and (S+P)F. Using (S+P)F in marine environment had positive effect on concrete strength properties in comparison with PC which was in 28 and 90 days about 12 % and 5 %, respectively. In marine environment, steel fibers had not meaningful effect on $f_{c(PC)}$. Minimum and maximum of f_{c7}/f_{c90} in marine environment was related to SFRC and (S+P) FRC for w/b = 0.4, respectively. By changing the w/b from 0.4 to 0.5 in 90 days age, the $f_{c(PC)}$ and $f_{c(SFRC)}$ were decreased about 18 % and 25 %.

At age 28 and 90 days and in marine environment, $f_{t(SFRC)}$ was increased about 15 % with w/b = 0.4 and 20 % in w/b = 0.5 rather than PC. Effect of steel fiber in increment of f_t in w/b = 0.5 was higher than w/b = 0.4. However, this effect was inconsiderable.

In laboratory condition and for f_c lower than the range of 20 – 40 MPa, $f_{t(SFRC)}$ and $f_{t(PC)}$ was approximately, same. Fibers role in increment of $f_{t(SFRC)}$ was started at range of 20 – 40 MPa for f_c about 1 – 19 % more than $f_{t(PC)}$. Considering the previous researches data and in laboratory condition a relation between f_c and f_t was proposed, $f_{t(SFRC)} = 0.3(f_c)^{0.7}$. For the same amount of $f_{c(SFRC)}$, the $f_{t(SFRC)}$ in marine environment was higher than laboratory condition.

$CSGR_{7\text{-}28}$ of PC and SFRC from laboratory to marine conditions was decreased about 10 % (was same for both w/b) and 15 % (for w/b = 0.4) and 20 % (for w/b = 0.5), respectively. $CSGR_{28\text{-}90}$ of PC and SFRC from laboratory to marine conditions was increased 10 % (for w/b = 0.4) and 5 % (for w/b = 0.5) and 10 % (for w/b = 0.4), respectively.

By adding the steel fiber to the PC in laboratory condition, $CSGR_{7\text{-}28}$ was increased 10 % which in marine environment $CSGR_{7\text{-}28}$ was increased 5 %. By adding the steel fiber to the PC, $CSGR_{28\text{-}90}$ was increased about 5 % which was same for both environments. The role of steel fiber in increasing the CGSR was inconsiderable. In marine environment, $CSGR_{7\text{-}28}$ and $CSGR_{28\text{-}90}$ for PC with w/b = 0.4 and 0.5 was approximately the same. In marine environment, by increasing the w/b from 0.4 to 0.5, the $CSGR_{7\text{-}28}$ and $CSGR_{28\text{-}90}$ of SFRC was decreased 4 – 11 %. Considering the previous mentioned researches, $E_{c(SFRC)}$ was lower than related $E_{c(PC)}$ and with increasing the f_c, the difference between $E_{c(SFRC)}$ and $E_{c(PC)}$ will be decreased from 2 to 30 %. Considering the previous mentioned researches, it can be proposed $E_{c(SFRC)} = 565\ f_c$ and the relation between $E_{c(SFRC)}$ and f_c will be linear.

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