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Effects of Hybrid Fiber on Flexural Behavior of Green RC Beams in Oman Sea

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ABSTRACT

Steel rebar corrosion because of the cracks in marine reinforced concrete (RC) structures is the main type of deterioration that leads to decrease the load-carrying capacity, ductility, and service life. The use of different fibers such as steel fiber (SF), glass fiber (GF), and polypropylene fiber (PF) in RC beams can reduce the cracks and increase the load-bearing capacity and toughness of RC beams. Moreover, it seems that RC beams containing hybrid of SF, GF, and PF have been higher flexural capacity and toughness rather than RC composites with only one type of fiber. However, the role of mono or hybrid fiber will be depended on environmental conditions. Consequently, load-bearing capacity and toughness of Green RC beam with 15% metakaolin (MK) as a cement replacement, containing SF, PF, GF, (S+P)F, and (S+G)F as fibers, at 28, 90, and 180 days in tidal zone of Oman Sea were determined. The dimension of the beams was 200×200×750 mm. The fibers included macro and microfibers. Macro fiber was steel with 50 mm length. Microfibers were GF and PF with 12 mm length. Results indicated that by the addition of PF, GF, SF, (S+P)F, and (S+G)F to RC beams the load-bearing capacity and toughness are increased up to 41%. Meanwhile, the hybrid effect of fiber was more than the mono one.

1. Introduction

Sustainable advantages of concrete and cement in CO_2 emission and energy consumption have been affected by the high volume utilization of concrete. The use of ordinary Portland cement (OPC) in concrete leads to about 8 and 3% of CO_2 emissions and the world's energy consumption, respectively [1][2]. On the other hand, SO_3 and NO_x considered too as greenhouse are released from cement manufactures [3][4]. Therefore, green concrete and generating less pollution are essential for concrete production. Indeed, compared to OPC, green concrete is defined as concrete that has less energy consumption and carbon dioxide emission. Against this background, the use of cementitious replacement materials will help to reduce environmental pollution by replacing part of cement in concrete and green concrete production. MK as a cement replacement is known to be a highly pozzolanic material. MK has a positive environmental impact and can improve concrete mechanical behavior. It reacts with hydrated cement and can reduce the concrete porosity and enhance the concrete durability [5].

Besides, the durability of concrete depends on its environmental conditions. Although marine environments are considered as a positive capacity for the transport industry, damage or deterioration of marine concrete structures is one of the main problems in this environment. Normally, marine concrete structures are divided into three zones. The first section, above the high tide line, is directly exposed to atmospheric air containing sea salts. In this part, cracking due to steel reinforcement corrosion and chemical reactions happens. The next part, between the high-tide and low-tide lines (tidal zone), is exposed to cracking, spalling, steel corrosion, material degradation, and physical damage. The last zone, which is situated below the low-tide all the time, is susceptible to material loss from the reaction of aggressive ions within the seawater [6]. Aggressive ions such as NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, and K_2SO_4 penetrate marine structures when cracking is occurred in concrete. Cracking by facilitating chloride penetration and other harmful ions can cause reduce the serviceability life, durability, and flexural capacity of concrete structures [7]. Therefore, any factor that reduces cracks can help to increase the bearing capacity, ductility, and durability of concrete structures in the sea environment.

Cracks at both micro and macro-levels can be limited by using fibers as reinforcement. At the micro-level, the initiation and growth of cracks will be limited. Moreover, at the macro-level, fibers will improve toughness and ductility by effective bridging and preventing cracks from unstable propagation. Hybrid fiber composites made by combining organic PF, inorganic GF, and SF have higher ductility and fracture toughness rather OPC or mono fiber composites. It seems that control of the micro-cracks and their growth in hybrid reinforced concrete is provided by small or soft fiber. Also, the second fiber (long or strong) arrest the propagation of macro-cracks and enhance the toughness of the composite. In another word, early age properties such as plastic shrinkage will be improved by small or soft fiber and mechanical properties will be enhanced by long or strong one [8][9][10][11].

The usage of fibers in RC has been evaluated by many researchers [12]. It has been found that shear, tensile strength, and fracture toughness will be improved by fibers addition to concrete. Glavind et al. [13] found that hybridization of SF and PF increases the ultimate compressive strain of concrete. Larsen et al. [14] tasted SF and PF hybrids on fracture energy of cementitious composites. They reported that fracture energy after 10 years in out-door exposure increases 40%. Bentur et al. [15] studied the effect of combined SF and PF concluded that the ultimate strength of composites is dependent on stronger and stiffer fiber while toughness and strain capacity are related to flexible and ductile fiber.

Banthia et al. [16] showed that composites reinforced with hybrids of PF and mesophase carbon fiber (CF) have the highest level of synergy in toughness. Mihashi et al. [17] found that hybrid fiber composites containing polyethylene (PEF) and SF show excellent performance against corrosion compared to mono fiber-reinforced composites. Caggiano et al. [18] tasted hybridization of SF and PF in cement composites. They concluded that post-cracking behavior is higher for hybrid fiber reinforced concrete rather than mono fiber composites. Huang et al. [19][20] reported that (S-P)F-RC specimens containing hybrid fiber have better bond strength in terms of peak bond strength and corresponding slip compared to mono fiber composites. Won et al., Yoo et al. and Li et al. [21][22][23] found that by the addition of fibers, the peak bond strength has a rise in slip.

Gali et al. [24] found that the early fracture response of hybrid fiber concrete is better than SF reinforced concrete. Sadrinejad et al. [25] studied the influence of hybrid fibers on serviceability of RC beams containing SF, Polyolefin (POF), and PF. they concluded that corrosion level of bars is reduced by the presence of fibers. Liu et al. [26] conducted chloride ion diffusion in concrete containing PF and GF. The results showed that chloride penetration in concrete is dependent on fiber diameter, the volume fraction of fibers, aggregate diameter, and volume fraction. Prathipati et al. [27] indicated that concrete containing hybrid GF and SF has higher distribution characteristics than mono fiber composites.

According to the above literature study, very few researches about the flexural performance of reinforced green concrete containing hybrid SF, GF, and PF in marine environments have been done. The aim of performed experimental tests, in this paper, is to study the flexural behavior of ordinary reinforced green concrete (RC) containing SF, PF, GF, hybrid SF and PF [(S+P)F] or hybrid SF and GF [(S+G)F] in the tidal zone of Oman Sea. Toughness and maximum force in force-deflection diagrams till 15 mm deflection are compared [28]. Considering the above paragraph, in this study, MK as a cement replacement is selected for green concrete.

2. Materials and methods

Ordinary Portland cement Type II and coarse aggregate with a maximum size of 19 mm were used in the present study. To remove dust and other fines the coarse aggregate was washed. It was graded based on ASTM C 33. The fineness modulus of sand and the sizes were 2.5 and 0 to 4 mm, respectively. Naphthalene Sulfonate Formaldehyde (NSF) as a Super-Plasticizer (SP) was mixed to get the required workability in concrete. MK as a cement replacement was added by 15% of the weight to cementitious materials. The water to cement ratio was 0.4. The style of concrete mixes was weight basis. The mineralogical composition of Portland cement, MK, and aggregates is shown in Table 1. Mixture identification and fiber types are indicated in Table 2. According to Table 2, for example, (R+P)C means RC beams containing mono PF, or (R+S+P)C indicates RC beams containing hybrid PF and SF. On the other hand, the total fiber volume fraction for all the mixes was 1%. The physical properties of fibers are given in Table 3. The fibers included macro and microfibers. Macro fiber was steel with 50 mm length.

Table 1 Chemical properties of the cement and MK

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	L.O.I	Na_2O	K_2O	Other
Cement (Weight ratio %)	21.9	4.6	3.9	64.5	2.6	0.8	0.3	0.9	0.5
MK (Weight ratio %)	53.2	44.54	0.82	0.08	0.04	0.9	0.2	0.04	0.18
Gravel	7.9	0.6	1.1	44.1	4.6	40.9	0.2	0.2	0.4
Sand	51.9	5.8	7.6	16.1	7.8	8.1	1.2	0.9	0.6

Table 2 Mixture identification and fiber types

Mix ID	Type of mix	Volume of various fiber types (%)			Total Vf
		PF	GF	SF	
RC	Plain	0.0	0.0	0.0	1.0
(R+P)C	Single fiber	1.0	0.0	0.0	1.0
(R+G)C	Single fiber	0.0	1.0	0.0	1.0
(R+S)C	Single fiber	0.0	0.0	1.0	1.0
(R+S+P)C	Hybrid fiber	0.1	0.0	0.9	1.0
(R+S+G)C	Hybrid fiber	0.0	0.1	0.9	1.0

Microfibers were glass and polypropylene with 12 mm length (Figure 1). The type of GF is alkali resistance RC beams have the same reinforcement details, four 10 mm diameter bars were used at beam bottom and top. 6 mm diameter stirrups at 65 mm.

Table 3 Physical Properties of fibers

Property	SF	PF	GF
Length (mm)	50	12	12
Diameter (mm)	0.55	0.022	0.014
Aspect Ratio	91	545	857
Elastic Modulus (GPa)	200	3.5-10	70-80
Tensile Strength (MPa)	1100	400-600	1400-1700

(AR). Fifty-four RC beams were cast and loaded under two points, using different percentages of fibers. The size of the beams was 200 × 200 × 750 mm.

(a) (b) (c)

Figure 1. Fibers are used in beams.

(a:) Steel Fiber, (b): Polypropylene Fiber, (c): Glass Fiber

RC beams have the same reinforcement details, four 10 mm diameter bars were used at beam bottom and top. 6 mm diameter stirrups at 65 mm. The reinforcement ratio was about 0.6%. The cover thickness for longitudinal and transverse reinforcement was 55 mm. The longitudinal and transverse reinforcements had a nominal yield strength of 400 MPa (Figure 2). Four-point loading was applied, producing a constant moment region of 210 mm in the middle of a 650 mm clear span. Loading was monotonically applied with a maximum capacity of 400 KN and the loads and deflections were simultaneously recorded.

The recording rate for mid-span deflections and the load was 1 mm/min. To obtain the net mid-span deflection, the support settlements were subtracted from the measured mid-span deflection by using LVDTs. After casting, specimens were cured at laboratory temperature for 28 days and carried to Oman Sea tidal zone (Figures 3 and 4). The temperature in the Oman Sea was (20-27) ▫C and the PH value was 7.66. The average compressive strength for 6 beams mixtures is 24 MPa, approximately.

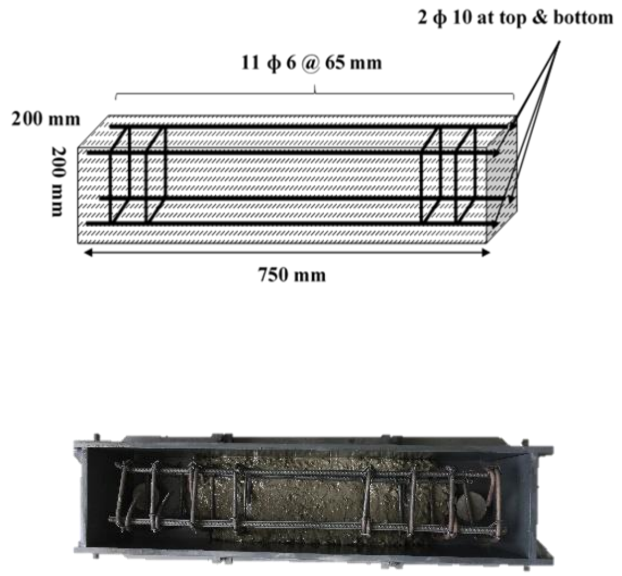

Figure 2. Details of tested beam reinforcement containing transverse and longitudinal reinforcement

Figure 3. Beam specimens in Oman Sea environment

Figure 4. Tidal zone in Oman Sea environment

3. Result and Discussion

The measured values were load and deflections and the calculated parameters were the max of bearing force and fracture toughness at 28, 90, and 180 days. Generally, the load-deflection diagram up to the specific deflection such as its maximum is named toughness. The toughness is an energy absorption capacity criteria for the flexural behavior of beams [29]. Achieve maximum deflection for calculating toughness of RC beams containing fiber is not easy. Therefore, in this paper, the maximum deflection was selected 15 mm for calculating the toughness, for all beams.

3.1. Effect of mono PF, GF, and SF on the toughness of green RC beams in Oman Sea tidal zone

Figure 5 shows the load-deflection diagrams for RC and (R+P)C beams at 28, 90, and 180 days in the Oman Sea tidal zone.

According to Figure 5, (R+P)C has 14 to18% higher force bearing capacity than RC beams in marine tidal zone till 180 days. On the other hand, toughness by adding PF to RC beams is improved by 10 to 13%. One of the most causes of service life reduction in marine RC structures is corrosion. The bearing capacity of marine structures will be decreased with aging due to reinforcement corrosion through concrete enlargement, cracks

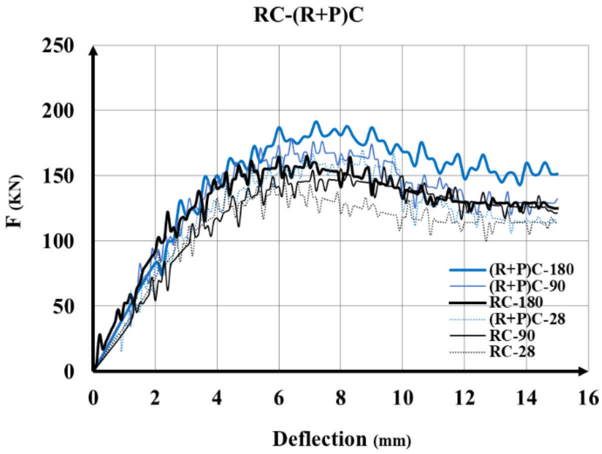

Figure 5. Load-deflection diagrams of RC and (R+P)C beams

the organization, or concrete cover spalling. Subsequently, a cross-section of corroded bars, ultimate strength of elements, and finally, ductility of marine RC structures will be decreased. Nevertheless, the toughness of marine structures by use of PF in RC structures will be increased. This is because of the delay in the corrosion initiation of steel [30][31][32], reduction bond between corroded steel and concrete [33] and prevent the widening of corrosion cracks [34]. Generally, one of the most synthetic fibers with easy dispersion that is made of monomeric C_3H_6, in various mixtures of concrete, is PF. The bold benefits of this fiber are cheap cost, ineffective property at high pH of the cementitious environment, and controlling plastic shrinkage cracking [35][36]. Ductility in RC structures containing fibers can be achieved by two different mechanisms: a) fiber composites can bear the plastic deformation or b) the plastic deformations are provided by bonding interface fiber/paste. In (R+P)C beams, since the fibers have not considerable debonding with round matrix, it seems that the first mechanism is happened [37]. On the other hand and based on the microstructure analysis, it seems that PF makes a network to limit the growth of CH crystalline, and thus, the microvoids, size, and orientation of CH are decreased. As a result, microstructures and the aggregate-cement interfacial transition zone of (R+P)C beams have less porosity and micro-cracking than RC. Also on the macro scale and flexural behavior of the beams, PF holds the concrete component together and resists physical damage and cracking propagation [38]. Moreover, MK through decreasing the porosity, as a cement replacement, helps cement paste to bond with PF, too [9]. Therefore, it seems that role of PF in increasing of bearing force and toughness of RC beams in terms of micro and macrostructures in the marine environment is noticeable.

Considering the load-deflection diagrams, calculated parameters were load carrying capacity and toughness for RC beams with or without mono or hybrid fiber in the Oman Sea tidal zone (Table 4). Figure 6 presents the two samples of concrete containing fiber and rebar after fracture.

Table 4 Maximum force and toughness values

Mix ID	P_{max} (KN)			Toughness (N.m)		
	28 (days)	90 (days)	180 (days)	28 (days)	90 (days)	180 (days)
RC	144.18	156.50	165.12	1617.87	1748.39	1894.58
(R+P)C	169.90	178.28	191.55	1792.12	1956.14	2144.96
(R+G)C	177.30	183.50	193.40	1859.11	1993.92	2158.59
(R+S)C	174.20	184.42	203.12	2003.24	2088.85	2344.15
(R+S+P)C	181.22	192.49	216.25	2082.41	2232.47	2529.64
(R+S+G)C	191.25	205.02	228.25	2213.89	2334.54	2674.79

(a)

(b)

Figure 6. Beam specimens at 90 days;

(a): (R+S+G)C, (b): (R+S+G)C

Figure 7 presents the load-deflection diagrams for RC and (R+G)C beams at 28, 90, and 180 days in the Oman Sea tidal zone

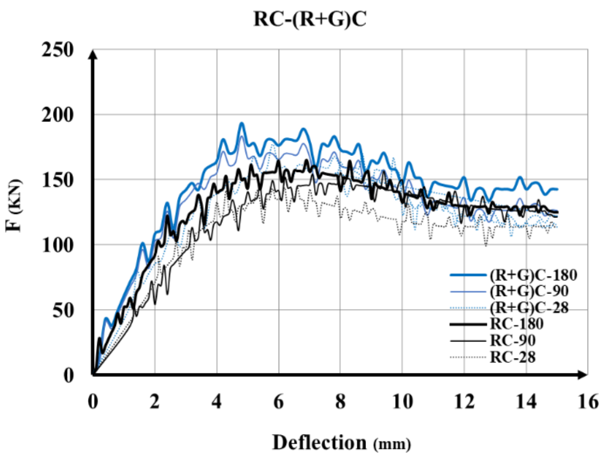

Figure 7. Load-deflection diagrams of RC and (R+G)C beams

As shown in Figure 7, (R+G)C has 17 to 23% higher force bearing capacity than RC beams in marine tidal zone till 180 days. On the other hand, toughness by adding PF to RC beams is improved by 14% approximately. Also load-bearing capacity and toughness of (R+G)C and (R+P)C is not considerable.

Generally, in concrete containing GF, after the hydration process, lime crystals and calcium silicate hydrates (C-S-H) penetrate the fiber bundles. Consequently, spaces between glass filaments are filled and the bond between glass filaments is increased. The result of bonding is embrittlement and lack of fiber ductility with aging [39]. A most beneficial method to prevent the adverse effect of GF in concrete is to use additive materials in combination with AR glass fiber. Among the materials used in cement paste, pozzolanic admixture by chemical reaction with $Ca(OH)_2$ produced in hydration, prevents the accumulation of these materials around the fibers and enhance the flexural behavior of the concrete[40][41][42][43]. Therefore, MK as a pozzolanic material and cement replacement help the GF to improve the toughness of RC beams.

Generally, transfer forces between concrete and rebar are provided by bonding strength as a remarkable structural property of RC beams. One of the main reasons for decreasing the load-carrying capacity of the structure is insufficient bond [44]. Chemical adhesion, friction, and mechanical interaction between the ribs of the bar and the surrounding concrete will determine the bonding strength. Based on previous researches strength is related to various factors such as concrete strength, concrete cover, and confinement of the concrete due to transverse reinforcement and bar geometry. It is expected that the bonding strength in RC beams containing fiber is more than the plain RC [8]. On the other hand and based on previous researches, since the diffusion coefficient of chloride ions in (R+G)C is less than (R+P)C [26], it seems that the permeability of (R+G)C is less than (R+P)C. Thereby, it is expected that due to less presence of aggressive ions and stronger bonding of GF rather than PF with surrounding cement matrix, the flexural capacity and toughness of (R+G)C are more than (R+P)C.

Figure 8 shows the load-deflection diagrams for RC and (R+S)C beams at 28, 90, and 180 days in the Oman Sea tidal zone.

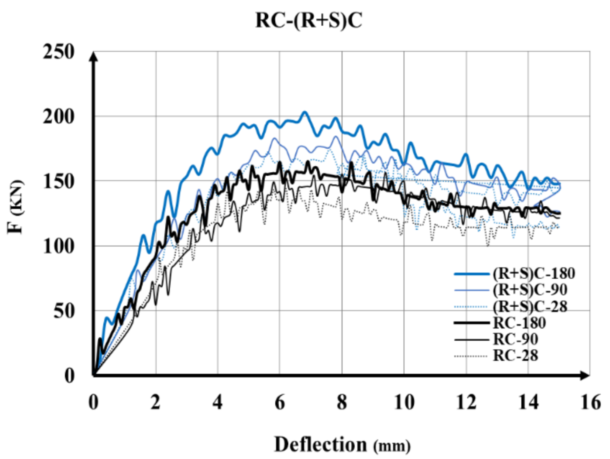

Figure 8. Load-deflection diagrams of RC and (R+S)C beams

According to Figure 8, (R+S)C has 20 to 23% higher force bearing capacity than RC beams in marine tidal zone till 180 days. On the other hand, growth in toughness by adding PF to RC beams is the same as force bearing capacity. The role of SF in transferring the tensile stress and inhibiting the crack width in concrete elements is bolder than PF and GF because of their physical properties. Generally, the role of SF in limitation of concrete cracks can be in micro and macro scales. At the micro-scale, the beginning of cracks can be stopped or its development can be prevented by SF. After the formation of macro-cracks, SF by providing effective mechanisms in bridging and reducing the rate of cracking, improve the toughness and ductility[45] [46]. While the role of PF and GF because of their length and other properties in arresting the micro cracks is more than macro cracks. Consequently, the load-bearing capacity and toughness of (R+S)C beams are higher than (R+P)C and (R+G)C.

Considering the marine environment, there is a doubt that corrosion of SF can be damaged the RC beams and load-bearing capacity and toughness will be decreased or not. It seems that SF with or without corrosion can increase the force-bearing capacity and toughness of RC in marine environments. The reasons for neglecting the negative effects of SF corrosion are:

a) Tensile forces from corrosion of SF is insufficient for applying force to surrounding cement matrix due to its little diameter.

b) If the crack width higher than (2-3) mm effect of corrosion is considerable [47].

c) In concrete beams containing SF, the formation of self-healing products is great.

d) In (R+S)C beams, the SF is dispersed randomly. Therefore connecting rebar and fiber in the cover zone of (R+S)C is possible. Thereby, the extension of the anodic region from rebar to SF will be possible. Hence, until the presence of hydroxyl ions, SF will be sacrificial anodic zone and corrosion in the cathodic region is happened. Consequently, SF will be corroded before rebar corrosion and other disconnected SF to rebar will be preserved by the cement alkalinity [48].

Therefore not only existence of little corrosion on SF causes a negative effect on fiber performance but also this phenomenon leads to an increase in the cement-fiber interface friction. On the other hand, based on previous studies, concrete beams containing SF have less chloride ion permeability than PF and GF reinforced concrete. Hence the rate of rebar corrosion in (R+S)C cylinder specimens is less than (R+P)C and (R+G)C [49][50]. Therefore the friction between a rebar-cement interface in (R+S)C is higher than (R+G)C and (R+P)C. Thereby, higher load-bearing capacity and toughness of (R+S)C beams rather than (R+P)C and (R+G)C is reasonable.

3.2. Effect of hybrid (S+P)F on fracture toughness of green RC beams in Oman Sea tidal zone

Figure 9 presents the load-deflection diagrams for RC and (R+S+P)C beams at 28, 90, and 180 days in the Oman Sea tidal zone

As shown in Figure 9, (R+S+P)C has 26 to 31% higher force bearing capacity than RC beams in marine tidal zone till 180 days. On the other hand, toughness by adding PF and SF to RC beams is improved by 28 to 14% approximately.

Generally and based on previous researches, the main effect of microfibers (such as PF and GF in this paper) is an improvement of the shrinkage and early cracks rather than arresting the macro cracks.

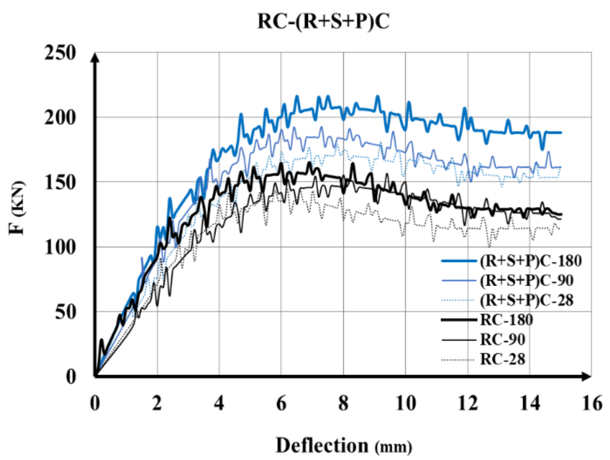

Figure 9. Load-deflection diagrams of RC and (R+S+P)C beams

In other words, it is expected that the effect of microfiber in ductility and impact resistance is less than the load-bearing capacity of concrete beams [51][52]. On the other hand, in hybrid fiber reinforced concretes (HFRC) by use of two or more different fibers achieve superior properties and better performance is possible [9].

According to previous studies, in HFRC, one type of fiber (generally microfiber) which is stronger and stiffer enhances the first crack stress and ultimate strength. Also, toughness, strain capacity, and ductility are related to the second type of fiber, which is more flexible and ductile in the post-cracking zone [51]. However, despite the benefits use of hybrid fiber in concrete elements, there is a significant problem in transition zone of HFRC [53]. In concrete containing mono fiber, there is a lot of porosity in thick transition zone which is more about HFRC [54]. Hence, reduction of porosity and consolidate this transition zone in fiber reinforced concrete, especially in HFRC will be essential and inevitable. Consequently, the use of materials that decrease the porosity in transition zone is one of the solutions. Nowadays, pozzolanic materials, which have cementitious character when composing with $Ca(OH)_2$ in water solution, is used as a Portland cement replacement in concrete for more consolidation of the cement matrix. Against this background, in this research, MK as a cement replacement can reduce the porosity in transition zones in HFRC and enhance the mechanical properties [9]. On the other hand, applying the MK will be helped to decrease cement and greenhouse gas.

Therefore, in (R+S+P)C composites, SF macro fiber by arresting the micro-cracks cause the toughness and ductility is improved. Meanwhile, shrinkage and early cracks are limited and delayed by PF micro cracks. In other words, the performance of micro and macro fiber complements each other.

3.3. Effect of hybrid (S+G)F on fracture toughness of green RC beams in Oman Sea tidal zone

Figure 10 shows the load-deflection diagrams for RC and (R+S+G)C beams at 28, 90, and 180 days in the Oman Sea tidal zone.

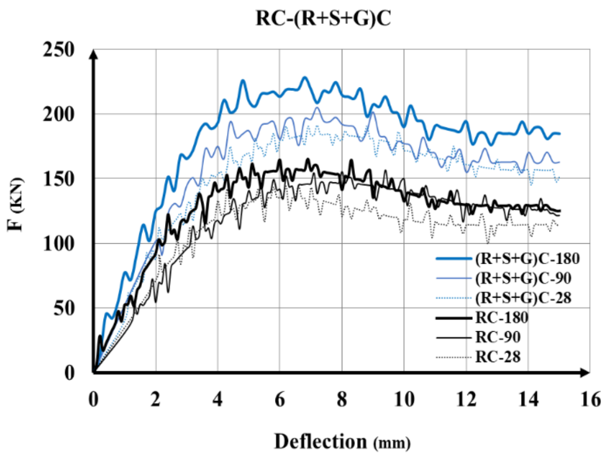

Figure 10. Load-deflection diagrams of RC and (R+S+G)C beams

According to Figure 10, (R+S+G)C has 32 to 38% higher force bearing capacity than RC beams in marine tidal zone till 180 days. Also, the toughness of RC by adding SF and GF is increased 37 to 41% approximately. Based on previous studies, the advantage of inorganic microfibers such as GF and metallic macro SF are achieving superior tensile strength, fracture toughness, and improvement of first crack strength [55]. Therefore, it is expected that (R+S+G)C will have a higher force bearing capacity and toughness rather than RC beams.

In RC beams, bonding between rebar and surrounding concrete is a significant parameter to transfer the force, strain compatibility, and composite action. By reducing the bond strength, load-bearing capacity and ductility will be decreased. Generally, bonding strength depends on chemical adhesion, friction, and mechanical interaction between the rebar and the surrounding concrete. On the other hand and according to previous studies, in RC beams with small diameter rebar, the role of fibers in bearing bond strength is not remarkable. But with increasing the rebar diameter, the confining effect of fibers with surrounding concrete and rebar will grow. Also GF has higher bonding with surrounding concrete rather than PF. Consequently, the confining effect of GF with rebar is higher than PF [8].

One of the unique properties of GF rather than PF is more uniform distribution in cement paste which leads to more cohesive behavior. Consequently, arresting the crack propagation in all directions will be more perfectly done. Thereby, the force required to pull out the fibers is increased and load-bearing capacity and toughness of (R+S)C by adding GF are grown [56]. Meanwhile, since the permeability and rebar corrosion rate of concrete containing GF against aggressive ions is lower than PF reinforced concrete, it is expected that bonding between rebar and surrounding concrete in (R+S+G)C will be higher than (R+S+P)C. Therefore, higher load-bearing capacity and toughness of (R+S+G)C rather than (R+S+P)C is justifiable.

4. Conclusion

This experimental research presented the study of load-bearing capacity and toughness of RC beams containing mono or hybrid fiber in tidal zone of the Oman Sea. Two types of mono fiber and three types of hybrid fibers were used. Mono fiber was PF, GF, and SF and hybrid ones were (S+P)F and (S+G)F. The hybrid beams were loaded until 15 mm deflection. The following conclusions till 180 days can be drawn:

1. RC beams containing PF have higher force bearing capacity and toughness (about 18 and 13%, respectively) rather than RC beams. On the other hand, GF causes an increase in force bearing capacity the same as toughness of RC beams (14% approximately). According to the little length of GF and PF and their main role in arresting the micro crack, the effect of these fibers on RC beams is about equal.

2- By the addition of SF to RC beams, flexural capacity and toughness are increased 23%. The more growth in mechanical behavior of RC rather than adding PF and GF is related to the role of SF in arresting the macro crack and more bonding strength of rebar with the surrounding concrete.

3- Effect of (S+P)F on load-carrying capacity and toughness of RC beams is higher (about 13 and 20%, respectively) than mono PF and GF. Due to the synergy role of macro SF and micro PF, this result will be justifiable.
4- RC beams containing (S+G)F compared to RC have 33 and 41% higher flexural capacity and toughness, respectively. This is because GF more bonding with surrounding cement paste rather than PF.

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