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The effects of polypropylene fibers on the properties of reinforced concrete structures

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ABSTRACT

In this study, the results of polypropylene fibers reinforced concrete properties have been presented. The compressive strength, permeability and electric resistivity of concrete samples were studied. The concrete samples were made with different fibers amounts from 0 to 2 kg m^{-3}. Also, the samples fabricated with coral aggregate and siliceous aggregate were examined and compared. The samples with added polypropylene fibers of 1.5 kg m^{-3} showed better results in comparison with the others. Moreover, coral aggregate concrete showed less electric resistivity and less compressive strength in comparison with samples fabricated of siliceous aggregates. It is concluded that the coral aggregates are not suitable for making concrete or using in concrete structures in the onshore atmosphere.

1. Introduction

In recent years, many studies have been conducted in the mechanical characteristics of reinforced fiber concrete. Such concrete is used in retrofitting and repairing the covering of concrete structure tunnels, carpentries stabilizing, etc. According to the researches, the increase of formability and bending strength are the extra advantages of adding the fibers to the concrete. Two kinds of fiber that very often used in the concrete are: steel fiber and polypropylene fiber [1,2]. The evaporation of concrete surface water is a factor in creating the contract paste fracture in concrete which leads to the formation of tension stress since the concrete starts to strengthen [1].

Zeiml et al. mentioned that using polypropylene fibers can improve spalling behavior of concrete. The paste fractures are formed when the acceleration of water evaporation is more than the movement of concrete emulsion to the surface. Here, the negative pressure is generated in the capillaries through which the concrete paste flows and proportionately the tension stress is formed. Such stress is developed during the concrete strengthening and the concrete is cracked where the stress is more than the concrete strength. The cracks caused by paste contracting in the concrete are formed in the first hours after pouring the concrete in the frames and before the concrete reaches its initial strength. Such cracks create critical points in the concrete sensitivity for attaching harmful materials to internal parts of concrete that finally can lead to corrosion and damaging the material in the concrete. Consequently, the performance, servicing or profiting capability, duration, aestheticism and strength of the concrete structures are reduced. Controlling the paste contract tracks in the concrete is of great importance in more duration and resistibility of concrete in the shortest time of structural utilization [3–6]. In ordinary concrete, where vibration is necessary, the best and most acceptable method for preventing cracks formations caused by paste contract is by using fibers, particularly thin artificial ones with the volume of less than 0.5% [7,8].

The results of the tests conducted by researchers showed that the compressive strength, tension strength and bending strength increased with higher fiber volume, while concrete liquefaction decreased [8–12]. One of the most important reasons for using the fiber reinforced concrete is elevating the tension stabilization and elasticity of the concrete obtained properly by using such special concrete. Developing the concrete characteristics by strengthening fiber has the following advantages:

1. Strength against cracks developing by contract dying and plastic.
2. Strength against moisture and thermal tension.
3. Increasing formability.

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4. Increasing strength against impulse and abrasion.
5. Reducing salt-water amount.
6. Reducing manual damage in transferring material, dry casted, to the application area.

All these advantages are pertinent to the kind of fiber as well as its concentration in the mixture; its high melting point (165 °C) and its chemical neutrality makes it strong acidic and alkali resistant. Polypropylene fibers have hydrophobic levels, which protect them against wetting with cement paste. The hydrophobic nature of polypropylene has no effect on the amount of water needed for concrete [7,13–15]. The characteristics of different fibers are listed in Table 1 [16]. Some scientists had studied the effect of chloride diffusion on rebar corrosion embedded into concrete that had caused deterioration of concrete structures [17–20].

In this study the influence of different amount of polypropylene fibers content on concrete properties were investigated by measuring permeability, electrical resistivity and compressive strength.

2. Methodology

2.1. Materials and sample preparation

The materials used in this project are listed in Table 2. The physical characteristics of polypropylene fibers are listed in Table 3. The mixture design mentioned in Table 3 was used for combining the initial materials. The concrete was put in column frames of 10 mm diameters with height of 200 mm for making samples, after mixing the initial materials in the rotating mixer and adding the fibers. In this research the concrete samples were prepared with fiber ratios of 0, 0.5 1.5 and 2 kg m^{-3}. In order to have a proper mixture design as well as the least penetration, the applied aggregates were graded according to the ASTM C33 standard [21]. The ratio of water added to the cement was $w/c = 0.48$. The concrete sample made up of coral aggregate was named CSP_0. The samples made up of siliceous aggregate were named $MSP_{0-2}L_{19}$. The detail of nomination is shown in Table 4. Specimens subjected for permeability and electrical resistivity were put in seawater environment.

Table 2
The raw materials used in the presented mixture design.

	kg m^{-3}
Water	190
Cement	400
Aggregate	1760
$\frac{w}{c}$	0.48

Table 3
Physical characteristics of polypropylene fibers.

Specific gravity	0.91 gr/cm^3
Diameter	22 μm
Width crossing	Circular
Melting point	160–170 °C
Water absorption	0
Torsion resistibility	400–350 MPa

Table 4
Nomination details of concrete samples.

M	Siliceous aggregate
C	Coral aggregate
S	Seawater
P	Polypropylene fibers
L_{19}	The size of used polypropylene fibers in mm
Index of P	Volume ratio of polypropylene

2.2. Determination of the permeability (K_T)

The importance of measuring the concrete moisture is to determine the gas permeability. Therefore, it should be conducted in such a way as to neutralise the moisture effects. In this regard the electrical resistivity ρ should be determined, which can be measured by the four electrode method. For this purpose, the circuit is between two external electrodes and the potential reduction is measured between the two internal ones. A repeatable laboratorial method is properly obtained by comparing the results of K_T, ρ and K_o (oxygen permeability factor) which can be applied for columns, the samples made up of different concrete mixtures of different amounts of moistures. The formulas (1) and (2) are used for dry concrete and moisture concrete, respectively.

$$K_o(T) = 2.5 \times K_T^{-0.7} \tag{1}$$

$$K_o(F) = 6 \times (K_T^{0.4}/\rho^{0.7}) \tag{2}$$

where $K_o(T)$ is the oxygen permeability calculated for dry concrete (E^{-16}m^2), $K_o(F)$ the oxygen permeability calculated for moisture concrete (E^{-16}m^2), K_T the gas permeability calculated by Torrent permeability test (E^{-16}m^2), and ρ is the electrical resistivity by Wenner method (kΩ cm).

The explanation for formula (2) is that a concrete cover being low in quality has high gas penetration (K_T) and therefore the low electrical resistivity ρ in ($K_T{}^{0.4}/\rho^{0.7}$) of formula (2) is affected by the quality. If the concrete cover is moisturized, the K_T and ρ are lower and therefore ($K_T{}^{0.4}/\rho^{0.7}$) is less affected. The system and equipments are shown in Fig. 1 [22].

2.2.1. Evaluating the quality of concrete cover

The system was primarily calibrated by a reference sample and used for testing. By putting a vacuum cell of two internal and external parts on the concrete surface and by closing the created vacuum facets, the internal and external parts are evacuated subsequently. After a certain time, depending on the permeability of concrete (the maximum of 720 s) the digital system would provide a number which is the permeability rate. The concrete quality was determined by comparing the number mentioned with the standard Table 4 shown below. The concrete cover quality of dry concrete was obtained by calculating the measures and putting the gained K_Ts in Table 4. For the moisture concrete, and where it is not known whether the concrete is moisture or dry, the ρ should be calculated in addition to K_T. Both these two rates should be mentioned in Fig. 2; the concrete cover quality is then determined.

This graph is based on formulas (1) and (2). The K_T zone is shown in Table 5. The effect of moisture on the gas permeability is presented in calculation of formula (2), so the values calculated by formula (2) are higher than those of formula (1) [22].

2.3. Measurement of electrical resistivity

A RESI electrical resistivitimeter made in Switzerland was used for electrical resistivity measurement of concrete with accuracy of ±1 from 0 to 99 kΩ cm and creating up to 180 MΩ cm current, micro frequencies up to 72 Hz and impedance up to 10 MHz. This device operates based on the Wenner method.

In this method the potential is measured by conducting the circuit on two external electrodes through two internal ones and then the strength is calculated using the following formula [23]:

$$\rho = 2\pi a(E/I) \tag{3}$$

where E is the electrical potential, I the electrical current, a the coefficient of electrical resistivity, and ρ is the electrical resistivity.

Table 1
The characteristics of different fibers [15].

Type	Specific gravity (gr/cm^3)	Tensile strength (MPa)	E (GN/m^2)	Elongation at failure (%)	Common V (%)
Polypropylene	0.91	550–700	3.5–6.8	21	<2
Steel	7.86	400–1200	200	−3.5	<2
Glass	2.7	1200–1700	73	−3.5	4–6
Asbestos	2.55	210–2000	159	2–3	7–18
Polyester	1.4	400–600	8.4–16	11–3	~0.065
Concrete, for comparison	2.4	2–6	20–50	–	0

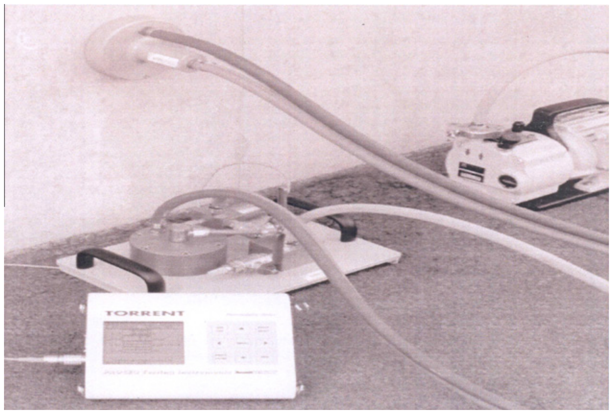

Fig. 1. Torrent system for permeability measurement.

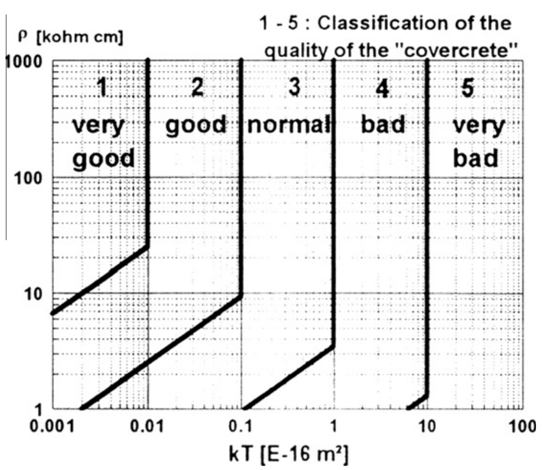

Fig. 2. Determination of concrete quality based on the permeability and strength [18].

Table 5
Concretes classification based on the permeability [18].

Quality of cover concrete	Index	$K_T(10^{-16}\ m^2)$
Very bad	5	>10
Bad	4	1.0–10
Normal	3	0.1–1.0
Good	2	0.1
Very good	1	<0.01

Ferreira and Jalali also used electrical resistivity as an NDT measurement and presented a prediction model for the 28-days compressive strength of concrete [24].

3. Results and discussion

3.1. Permeability of concrete samples with different volume ratios of polypropylene

The permeability results of this comparison are listed in Table 6. The reason for high level of permeability on the first day when the samples were taken out of the frames was most probably because the samples were not properly operated. In this regard, it was shown that samples with fibers had lower permeability in comparison with those without fibers. This is because the fibers prevent the concrete from cracking growing by forming connection bridge [25]. According to Table 5 and Fig. 2, it is clear that concrete with the amount of polypropylene fibers of 0.5, 1.5 and 2 kg m^{-3} have more acceptable K_T than other compositions considered in this study. Therefore, it can be said that permeability is the main factor that is responsible for diffusion of chloride ion as an aggressive element in concrete.

Table 6
Permeability factor of different concrete samples immersed for periods of up to 3 months in seawater.

$K_T(\times 10^{-16}\ m^2)$						
Time (day)	Concrete samples					
	$MSP_{0.5}L_{19}$	MSP_1L_{19}	$MSP_{1.5}L_{19}$	MSP_2L_{19}	MSP_0	CSP_0
1	6.962	2.58	3.2	3.01	8.25	13.58
5	0.062	0.160	0.046	0.038	0.083	0.58
9	3.692	0.173	0.119	0.150	0.091	0.335
15	2.563	0.150	0.131	0.103	0.031	0.05
25	2.413	0.068	0.025	0.015	0.03	0.04
30	0.082	0.061	0.007	0.007	0.122	0.974
35	0.115	0.045	0.093	0.073	0.64	0.111
40	0.039	0.614	0.077	0.047	0.103	0.106
62	0.810	0.301	0.234	0.135	0.894	0.435
92	0.024	0.905	0.03	0.07	1.06	0.98

3.2. Compressive strength of concrete

Researchers investigated the effect of adding fibers on the concrete mechanical properties in different condition [12,26,27]. As far as this study was concerned, the concrete samples made for a compressive strength test were put in 25 °C and water media (100% moisture) for 28 days. The results of compressive strength are given in Fig. 3. The concrete samples made up of coral aggregates showed the least compressive strength. For the samples made up of siliceous aggregate, the compressive strength increased with the increasing amount of polypropylene up to 2 kg m^{-3}. It can be seen in Fig. 3 that the siliceous aggregate concrete samples with fiber volume ratio of 1.5–2 kg m^{-3} show significant increase in compressive strength. Topçu and Canbaz also demonstrated that fibers could reduce crack formation and development and thus led to increasing compressive strength [28].

The microscopic image was taken from one of the samples having propylene fibers in order to scrutinize the fibers effects on the cracking and strength of the concrete. From micrographs in Figs. 4 and 5, it is clear that the fibers are located in the width of formed crack and creating the connection bridges. The characteristic of fibers prevent the separation of concrete pieces after cracking. Fig. 5 is a graphical schematic representation of how fibers can make the connection bridge and prevent crack propagation.

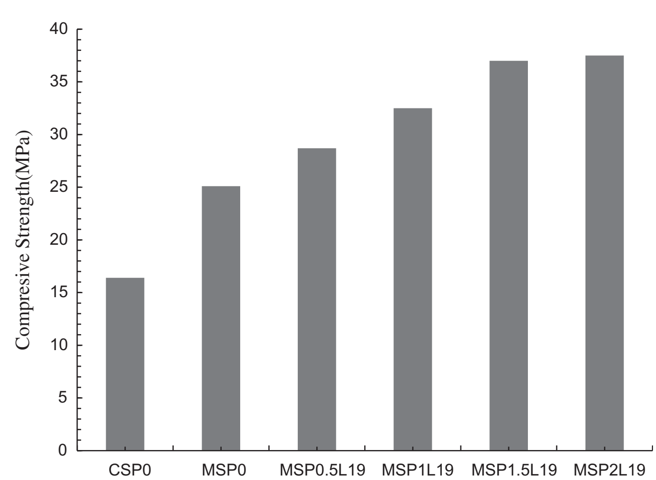

Fig. 3. Compressive strength of different concrete samples after 28 days curing.

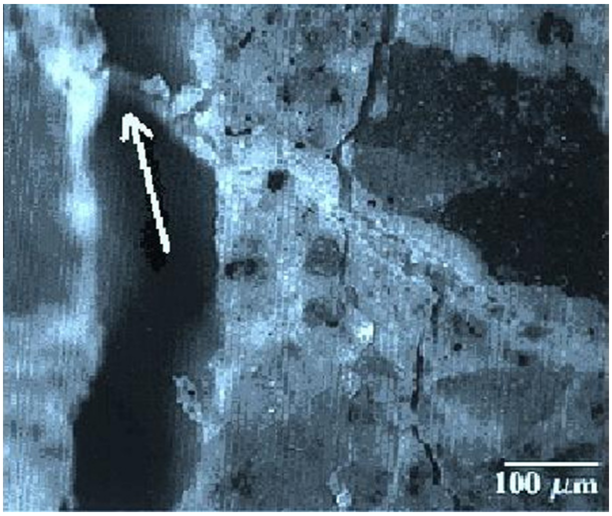

Fig. 4. Microscopic picture of the intersections of fiber and crack formed on the concrete surface.

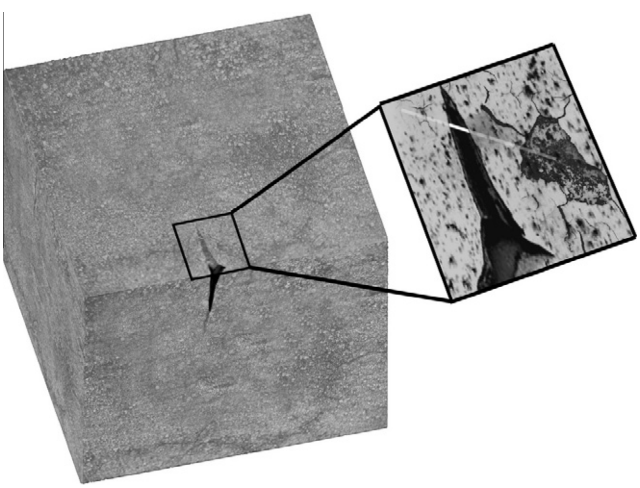

Fig. 5. graphical schematic of the prevention of the crack propagation by forming connection bridge by fiber.

Table 7
Electrical resistivity of concrete samples with different volumetric ratio of polypropylene fibers.

	$MSP_{0.5}L_{19}$	MSP_1L_{19}	$MSP_{1.5}L_{19}$	MSP_0	CSP_0
ρ(kΩ cm)	13–14	14–19	11–18	14–15	11–14

3.3. Electrical resistivity of concrete samples with polypropylene of different volume ratios

The results of the measurement are listed in Table 7. The electrical resistivities of concrete samples with fiber ratios of 1 kg m^{-3} and 2 kg m^{-3} have higher values in comparison to the others which affect directly the reduction of reinforcement corrosion. The samples made up of coral aggregate had the least electrical resistivity, which indicated lower resistivity of concrete against the current. The resistivity reduction was due to the chloride present in coral aggregate. Concrete electrical resistivity acted as a "controlling" factor of the reinforcement corrosion rate, since corrosion was the main factor that was responsible for concrete deterioration in onshore structures [29–31].

4. Conclusion

i. From this study, it could be clearly seen that coral aggregate was not a suitable component for concrete structure because of its high electrical resistivity and low compressive strength.
ii. According to the results of compressive strength tests, the concrete compressive strength increased proportionately with the increase in volume ratios of propylene fibers, the highest strength values were seen in the volume ratios of 1.5 kg m^{-3} and 2 kg m^{-3}.
iii. The presence of polypropylene fibers had caused delay in starting the degradation process by reducing permeability, reducing the amount of shrinkage and expansion of concrete that can significantly affect the lifespan of the structure.
iv. Electrical resistivity of concrete samples with fibers ratios of 1 and 1.5 kg m^{-3} had higher values in comparison with other samples. It has direct effect on the corrosion reduction of rebar.
v. In general, the samples with fibers content of 1.5 kg m^{-3} showed optimum results in comparison with other samples in this study.

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