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Use of polypropylene microfibers to improve mass concrete by controlling the crack sealing mechanism

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Keywords: Self- repair, Mass concrete, polypropylene microfiber, mechanical properties.

Abstract

Because cracks are the main problem of mass concrete, this paper investigates an experimental study on the effect of polypropylene microfiber (PPMFs) on self -repair behavior of mass concrete, through study the microstructure, workability, physical, and mechanical properties of mass concrete. PPMFs with a diameter of 18 µm add in different percentages (0, 0.5, 1 and 1.5) % of cement weight. Where the prepared mixture ratio was (1:2:4.8) and the water-cement ratio (W/C) was 0.4. Also, 0.6% of Superplasticizer (SP) % of cement weight to all concrete mixtures was added. In this study, an SEM analysis used to observe the effect of PPMFs on microstructure of mass concrete, and compressive and flexural strength tests for study mechanical properties of this. And referring to the analysis and discussion of the results, PPMFs used have changed microstructure of mass concrete, and have an effective effect on improve compressive strength and flexural strength, and mechanism of sealing the cracks of concrete autogenously. Also, 1% PPMFs (% of cement weight) recorded as the highest addition, which has a positive effect on mass concrete properties to apply it in the construction field.

Keywords: Self- repair, Mass concrete, polypropylene microfiber, mechanical properties.

1. Introduction

Cracks are the most common problem in mass concrete structures, such as concrete for dams, large piers, and foundations. Due to the low surface-to-volume ratio, most cracks are formed by the heat of cement hydration. Through the construction process, the temperature of the concrete will rise due to the exothermic reaction of the cement. This is especially a problem in mass concrete structures, which are most likely to thermal cracking at an early age due to the heat of hydration of cement. Because the surface of the structure radiates heat into the atmosphere, a thermal gradient occurs between the cold exterior of the structure or element and the warm core. Differences in free thermal expansion between parts of the structure will cause tensile stress on the surface [1-4]. If these stresses exceed the tensile strength of the concrete, cracking can occur. This is a common problem in engineering practice and may be exacerbated by adverse environmental conditions during the concrete pouring and curing process [3].

Numerous researches have been carried out on modifying the components of concrete, including change in cement matrix components by incorporation different types of fibers, like steel fiber, carbon fiber, polyethylene fiber, PVA fiber, and polypropylene fiber. Microfiber improves the structural integrity of the concrete, where previous research results showed the adding fibers to concrete mixtures results in crack reduction, durability improvement, superior ductility, better energy absorption, and tensile strength enhancement. According to Pavel et al. [5], the addition of a small amount of carbon fiber improved the compressive and bending strength of concrete. In another study, H. AWANG et al. [6] observed samples containing numerous fibers achieved higher compressive strength, tensile splitting strength, flexural strength, lower absorption and lower shrinkage readings than the control sample. Besides, the influence of fibers on cyclic freezing and thawing of concrete studied, when Piotr et al. [7] improved the scaling resistance significantly by using polypropylene and steel fibers. Also, evaluated the effect of different types of microfibers on thermal properties of cementation materials was determined [8].

Many researchers studied the effect of different types of microfibers on tighten crack width, for example, Shunzhi et al. [9] who studied the performance of self-repairing for ECC materials that included steel and wool fibers. And Zengzhi et al. [10] used SEM analysis to investigate the microstructure of FRC where observed Polypropylene fibers acted as network that bridge cracks after the first cracks occur, so preventing it from growing and supplying some warning time. Also, microfibers provide high bonding strength as shown by Moosa et al. [8] when studying the influence of the bond between microfibers and cement matrix on mechanical properties [11]. From previous mention, most of these researches applied the microfibers in various cementation systems, but not applied in mass concrete class, as shown in this study. That investigated the effect of polypropylene microfibers on the restoration of the mechanical properties, and self-healing ability, after form micro-cracks in prism samples during flexural strength test, then observing decrease the crack width during the curing period.

The objective of this study is to fabrication a concrete mix suitable for mass concrete applications that have the ability for self-repair. where prepare number of concrete samples contain different rates of polypropylene microfibers, to observe the effect of these additives on the efficiency of self-healing, through study the microstructure, physical, and mechanical properties of them.

2. Materials and Experimental Work:

This work consists of two routes, the first includes incorporating of microfiber PPMFs with concrete in three different percentages (0.5, 1and 1.5 wt % of cement weight), and then studying the influence of PPMFs on the performance of concrete. The second routs include making micro-cracks in concrete and studying the influence of PPMFs on mechanism and period of the seal of these cracks.

2.1Materials and Prepared Samples Test:

2.1.1 Materials:

As shown in Fig. 1 PPMFs was supplied by Sika Fiber complied with ASTM C1116. Table 1 shows the typical properties of PPMFs at 25 °C. Aggregate of Najaf was used in the preparation of Mass concrete, Crushed coarse aggregate with maximum particle size 40 mm (according to BS 5328-2:2009), and gradation of fine aggregate with the limits of zone1, Table 2,3 shown the properties of aggregate, and their grading that meets British standards BS 882:1992, respectively. Sulfate-resistant cement (SRPC) is used in the preparation of mass concrete; Table 4 summarizes the properties of SPRC. In all mixtures added 0.6% of cement weight by Superplasticizer as a chemical additive to reduce water of mixing amount, which carry trade name Sika viscoCrete -5930 L, which has form as viscous liquid and with basis as aqueous solution of modified polycarboxylate and has appearance like turbid liquid with density 1.1 g/cm3, which is identical to the British specification EN 934-2:2001. Potable water that has PH = 7.5 used for mixing and curing all samples in this study.

Fig.1 PPMFs

Table 1 Typical Properties of PPMFs at 25 C

Property	Value
Component	Single
Form	Fibrous
Color	White
Specific gravity	0.92+/-0.02
Standard length	3,6,12 and 18mm
Tensile strength	350 N/mm2
Modulus of Elasticity	5000 N/mm2
Elongation at break	25%
Softening point	140°C
Melting point	160 °C
Alkali Resistance	Excellent

Table 2 The properties of Fine and Coarse Aggregate chemically and physically

Properties	Fine agg.	Coarse agg.	B.S limits EN 12620:2013
Specific gravity	2.63	2.5	2.4-2.8
Dry compacted density(mg/m^3)	1.6	1.78	1.12-1.78
Water Absorption %	0.86	1	-
SO_3 %	0.038	0.08	$\leq$ 0.2
Fineness modulus	2.7	2.7	-

Table 3 Grading of Fine and Coarse Aggregate and Requirements

B.S. sieve percentage by weight passing			B.S. sieve percentage by weight passing		
Fine agg.			Coarse agg.		
(in)	(mm)	Grading zone 1	(in)	(mm)	11/2-3/16 (in), 38-5 (mm)
3/8.	9.52	100	3	76.2	100
3/16.	4.76	90/100	21/2	63.5	-
NO.7	2.4	60/95	11/2.	38.1	95/100
NO.14	1.2	30/70	3/4.	19.05	30/70
NO.25	0.6	15/34	1/2.	12.7	-
NO.52	0.3	5/20.	3/8.	9.52	10/5.
NO.100	0.15	0/10.	3/16.	4.76	0/5

Table 4 Chemical Composition and Main Compounds of SRPC

Oxides Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	L.O. I.	Insoluble residue	L.S. F	C_3S	C_2S	C_3A
Content %	60.69	20.4	5.7	3.12	2.86	1.8	3.23	1.09	0.77	41.7	27.5	10
Limits of B.S 4027	-	-	-	-	<5	<2.5	<4	<1.5	-	-	-	-

2.1.2 Mix Proportion:

The mixing proportion was according to British standards B.S 5328-2-1997. Table 5 includes details of the mixing ratios of 1m^3 concrete grades C20.

Table 5 Proportions of Mix in Kg/m^3

	Type	**PPMFs** (Kg/m^3)	**Cement** (Kg/m^3)	**Fine agg.** (Kg/m^3)	**Coarse agg.** (Kg/m^3)	**Water** (Kg/m^3)	**SP** (Kg/m^3)
1	Control	0	280	576	1344	112	1.68
2	0.5% PPMFs	1.4	278.6	576	1344	112	1.68
3	1%PPMFs	2.8	277.2	576	1344	112	1.68
4	1.5% PPMFs	4.2	275.8	576	1344	112	1.68

- Mix ratio 1:2:4.8

2.1.3 Preparation of Mixes and Casting:

After weight raw materials for concrete components which it is details shown in Table 5, fine aggregate, cement, and coarse aggregate dry-mixed by concrete mixer for three minutes then added SP and water which add with it PPMFs for dry mixture, and mixed for two minutes, After that, was oiled the inner sides of the molds with a thin oil layer, to take the specimens of concrete out easily at later, Then, concrete mixture poured in the prism molds with dimensions of (75*75*300) mm according to BS 12390-5-2009 for flexural strength test, and in cube molds with dimensions of (150 *150*150) mm according to BS 1881-116 for compressive strength test.

The mixing process was done at normal conditions where the ambient temperature was 27°C, and the treatment process was in moist condition by immersion the hardened specimens after remove from molds in water tank according to BS standard 1881-Part 111.

2.2 Tests:

2.2.1 Fresh Concrete Workability:

To detect the effect of PPMFs on the workability of concrete, the same amount of W/C and SP was applied to all concrete mixtures, and through slump testing, this effect can be inferred, as in this test a cone can be used with dimensions of (300 × 100 × 200) mm (height of cone, diameter of top and base cone) respectively, according to BS1881-102 1983.

2.2.2 Physical Properties:

Dry density, Porosity, and water absorption can be determined according to ASTM (C642-97). Parts from crushed concrete samples in compressive strength test are used in this test. Firstly when samples are received takes the first weight for its, then the samples were immersed in water for one day. After that, weighed samples again after it takes off from water and recorded as second weight. Finally, determines the third weight the samples which submerged in water, the results of these tests can be calculated from the following equations:

Dry density (g/cm^3) = $[w_1 / (w_2 - w_3)] * \rho_w$ …. (1)
Absorption of Water = $[(w_2 - w_1)/w_1] * 100\ \%$ …. (2)
Porosity = $[(w_2 - w_1) / (w_2 - w_3)] * 100\ \%$ …. (3)

Where, W_1: Weight of dry sample (g); W_2: Weight of wet sample (g); W_3: Weight of the submerged sample in water (g); ρ_w: Density of water, which is equal to 1 (g/cm^3).

2.2.3 Compressive Strength Test:

A compressive strength test was done according to B.S.1881-116, in this test use a compressive strength test machine (TONI PACT 3000/Germany). The loading rate was about 0.25 MPa per sec. The average result of three prepared concrete specimens with dimensions (150×150×150) mm was reported for each mixture, and this test applied on 7 and 28 days age, using the following relationship for determining compressive strength.

$\sigma = P/A$ ….. (4)
Where, σ: Compressive strength, MPa; P: Ultimate compressive load, N; A: Sample area, mm^2

2.2.4 Flexural Strength Recovery Test:

Three-point bending is examined according to BS EN 12390-5: 2009 standards , before test, a notch is made to a depth of 3 mm below each prism at mid-base by use a diamond circularly saw, notch act as stress concentration points for control spreading cracks at the tip of it. The download speed was 0.04 mm/min. The mean results of three prepared concrete samples were recorded with dimensions (75×75×300 mm) at 7 days of age. and when complete the test, samples were re-immersed in the water tank vertically to keep the surface of the crack in contact and leave for further 28 days [6], the bending strength can be determined for (1st R) and (2nd R) from Eq. (5):

$$F_{ct} = \frac{F*I}{d_1*d_2^2} \quad .... (5)$$

Where, F_{ct}: is the flexural strength, in MPa (N/mm²); F: is the maximum load, in N; *I*: is the distance between the supporting rollers, in mm; d_1 and d_2: are the lateral dimensions of the specimen, in mm.

To evaluate flexural strength recovery, the same prism samples are tested from both mixtures again after healed for 28 days from initiate the first cracks (2nd R), and through applicant Eq. (6):

$$\text{Efficiency of healing}\, \eta\% = {f_{ct1}}/{f_{ct2}} \quad .... (6)$$

Where, η%: is efficiency of healing; f_{ct1}: is maximum stress of original sample (1st R); f_{ct2} is maximum stress of healing sample (2nd R); crack detection microscope was used to analyze the crack seal at various times. Every week removed samples from the water to measure the width of the crack, and to take photography to estimate % strength recovery over time. The cracked prisms were marked where readings were determined.

3. RESULTS AND DISCUSSION:

3.1 Slump Test Results:

The slump test results for all mixtures in Fig. 2 show that they are related to the content of PPMFs. The test value decreases significantly as the content of PPMFs in the mixture increases, slump value for 1.5% PPMFs sample was reach to 74 mm, while the slump value of mass concrete (max size aggregate 40 mm) is 75 mm according to BS 5328-2-1992. The decline of mobility occurs principally due to PPMFs preventing the relative movement of mixture particles, this result corresponds with previous research [12].

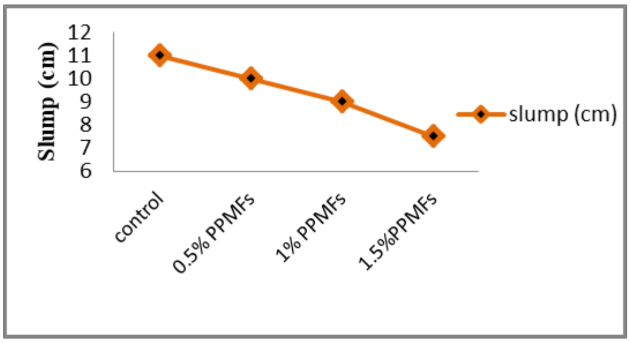

Fig.2 Slump Test Results for all Fresh Concrete Mixtures Samples

3.2 Mechanical Test Results:

Fig. 3 shows the compressive strength test results at ages 7 and 28 for all cube samples and the results of the test in Fig. 3 represent as average for each three samples. wherein the results of early age (7 days age), the all-added mixtures showed an increase in compressive strength when compared with reference sample, all mixtures (reference and all PPMFs mixtures) excessed the target strength of 20 MPa at the age of 28 days, Development of compressive strength of all samples may return to the effect of high-performance Superplasticizer (Sika ViscoCrete 5930l) which represent as a parameter that lower water-cement ratio that required in concrete mixture preparation, also this phenomenon is likely to occur because the type of cement (SRPC) used in the mixture which has less C_3S content, linked with development in strength at early age and high C_2S content associated with long-term age strength development.

Moreover, the mixture which has 1% PPMFs exhibited significantly the highest compressive strength at both ages 7and 28 days, respectively, however, but when exceed %MF over 1% the reduction in strength occurs at all curing ages, The same effect occurs with the flexural strength test, where according to results of compressive strength, prism with1% PPMFs were chosen to compare with reference samples to predict flexural strength results, the prism with 1%PPMFs reached to the highest result 14.6 MPa at age 7days, while the reference sample did not exceeded 13.54 MPa at same age [12, 13,14].

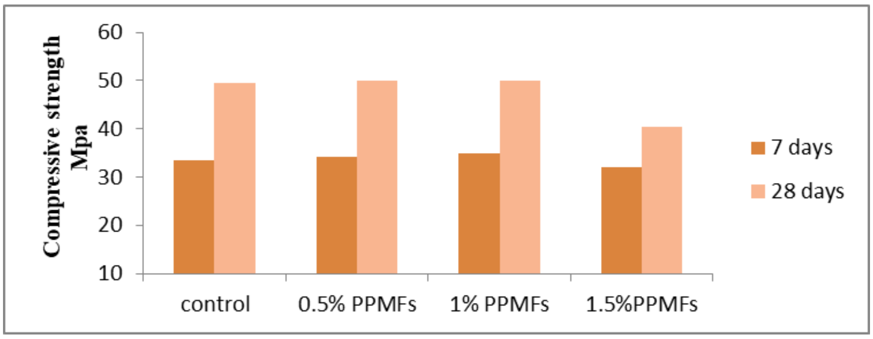

Fig. 3 Results of Compressive Strength Test for all Samples

To assess the flexural strength recovery, prism specimens from the two mixtures which cracked after 7 days of water curing (1st R) return to further curing for 28 days, then test again (2nd R), Fig. 4, and According to Eq. (6), this could illustrate that the PPMFs and reference specimen recovered 91.1% and 72.38% of their original flexural strength (1st R) respectively, Fig. 5, this is an indication of the efficacy of using PPMFs as a healing agent when compared with the control specimen [9].

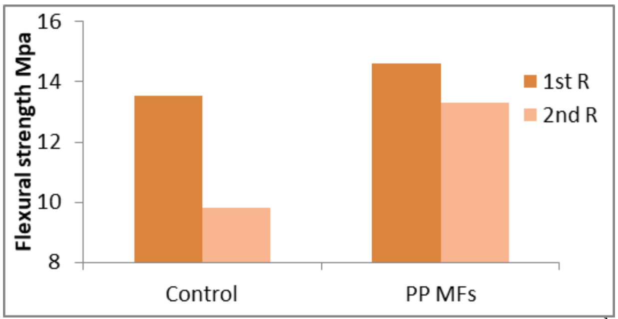

Fig. 4 Curve of Flexural Strength Values at 1^{st} and 2^{nd} R

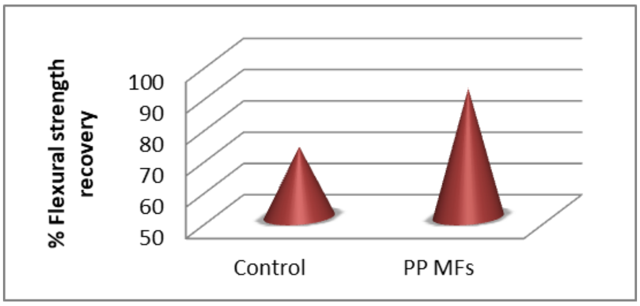

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Fig. 5 Percentage of Flexural Strength Recovery of Samples with and without PPMFs

3.3 Evaluation of seal of crack by microscopy:

After forming the cracks in all samples at 7days age, and after 28 days of healing in water, since fabricating initial cracks, observed cracks by microscope. Where the percentage of healing values after 28 days for control sample and PPMFs sample are shown in Fig. 7, also Fig. 8 shows the shape of the cracks observed by the microscope, and the best reduction in crack width was at a PPMFs specimen, as shown in Fig. 6, where PPMFs act as bridges, allow to un hydrated Cementitious Material to initiate continuous reaction during the period of self-healing and tighten cracks width [2, 9].

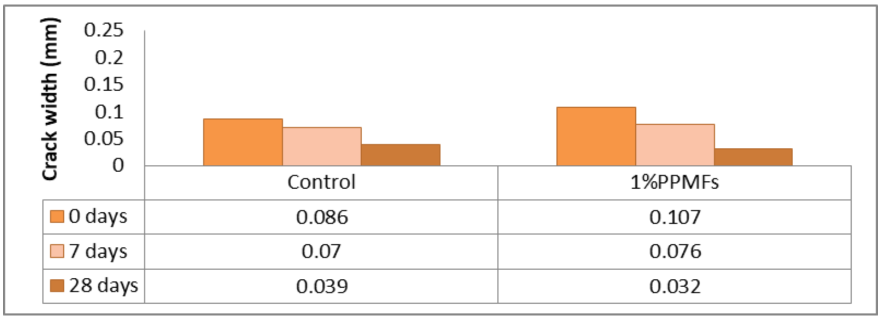


Fig. 6 Reduction of Crack width with the Time of Healing for prism Samples

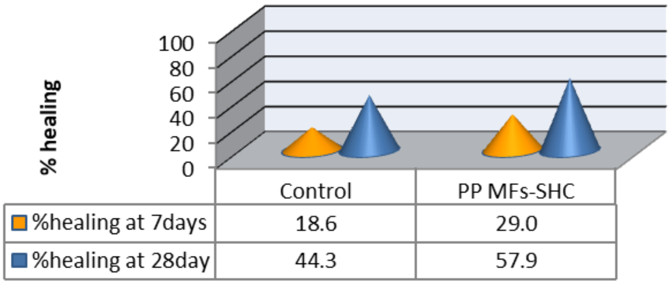


Fig. 7 Percentage of Sealing of Cracks for prism Samples after 7, 28 day of Healing Period

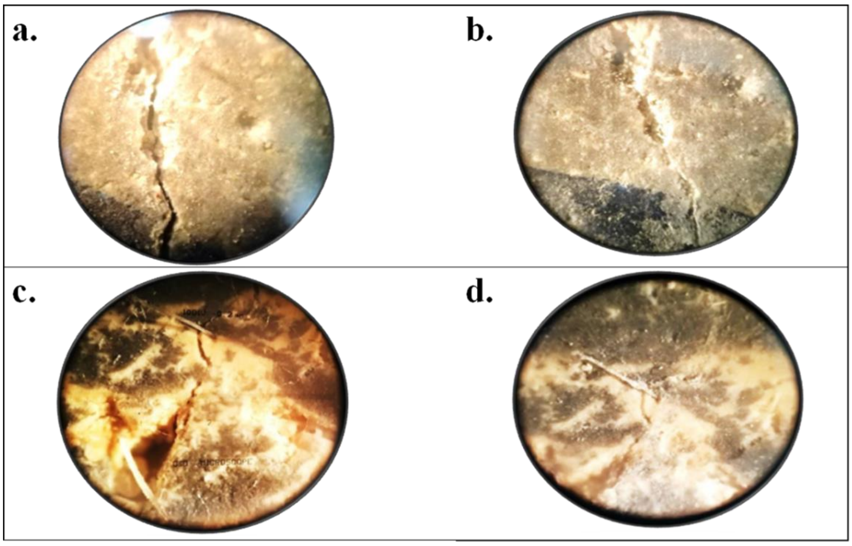
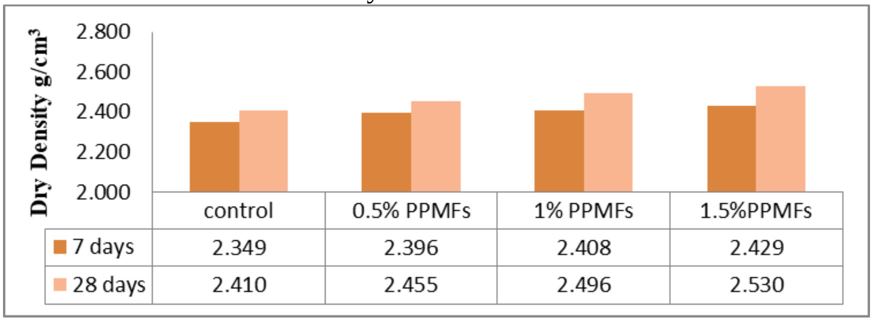


Fig. 8 Cracks before healing (left) and after healing (right) (a and b: control specimen) (c and d: PPMFs specimen)

3.4 Physical Properties Results:

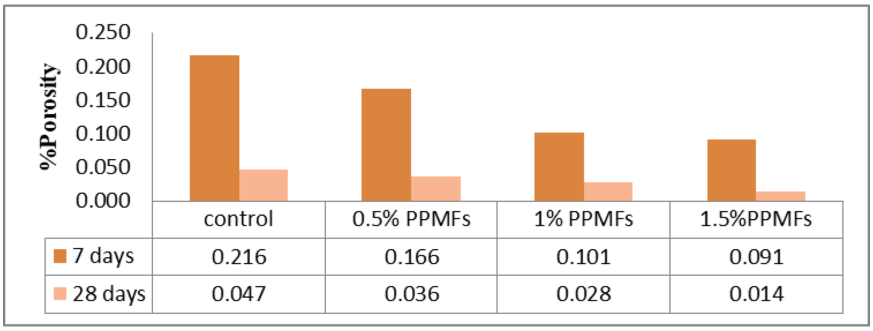
According to experimental methods for examining the physical properties of all concrete mixtures, the dry density increases with an increase of % PPMFs at 7 and 28 days age as shown in Fig. 9 [10,15], porosity and water absorption results provided decrease with increase of %PPMFs [10] Fig. 10 and 11.

Results indicate that PPMFs significantly densest the microstructure of concrete, and largely reduces voids causing in reduce absorption, led to enhance from mass concrete properties as observe later in mechanical tests in this study.



	control	0.5% PPMFs	1% PPMFs	1.5%PPMFs
7 days	2.349	2.396	2.408	2.429
28 days	2.410	2.455	2.496	2.530

Fig. 9 Dry Density of all Concrete Samples



	control	0.5% PPMFs	1% PPMFs	1.5%PPMFs
7 days	0.216	0.166	0.101	0.091
28 days	0.047	0.036	0.028	0.014

Fig. 10 Percentage of Porosity for all Samples

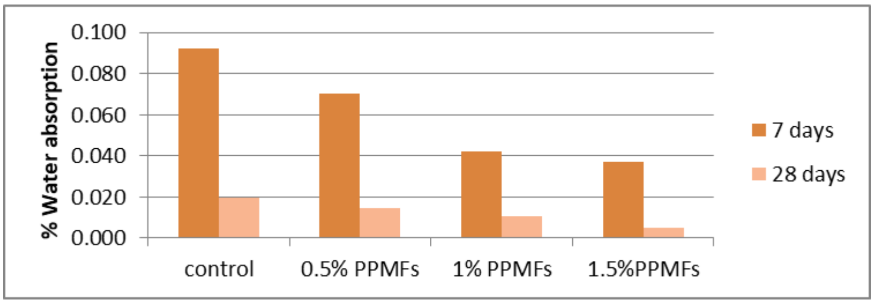


Fig. 11 Percentage of water absorption of all samples

3.5 SEM Results of Concrete with and without PP MFs:

Figures 12 and 13 display SEM images of the control sample, and mixed sample (0.5, 1, 1.5)% PPMFs, after compression strength testing of cube samples at the ages of 7 and 28 days, cracked samples return in water tank to further 28 days, and using SEM to analyze crack area. Results shown PPMFs change mass concrete microstructure, the grain size increases, and CSH gel expands as healing compounds until it fills almost all voids, due to the effect of the bridge, which is produced by PPMFs, that enhance heal the cracks autogenously. While in Fig. 12 concrete without PPMFs, a gel was observed but containing porosity because the reaction is incomplete.

Also in Fig. 13 (b), optical testing of the microstructure of the sample containing 0.5% of PPMFs showed the appearance of nanoparticles compared to the usual concrete model, that's because PPMFs form a network that restricts the growth of calcium hydroxide, causing dense microstructure and shrinking fine voids by further expanding the CSH gel. [9, 10]

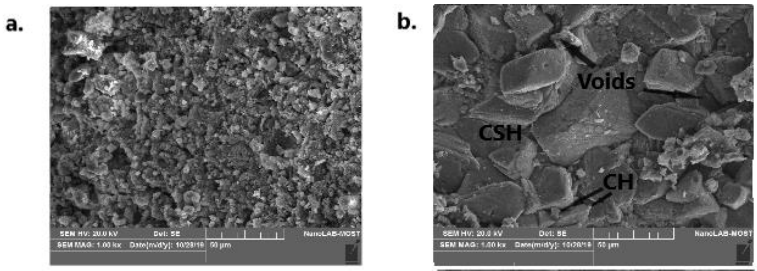


Fig. 12 SEM for Control Sample after heals during 28 days (7 days age on left) (28 days age on right)

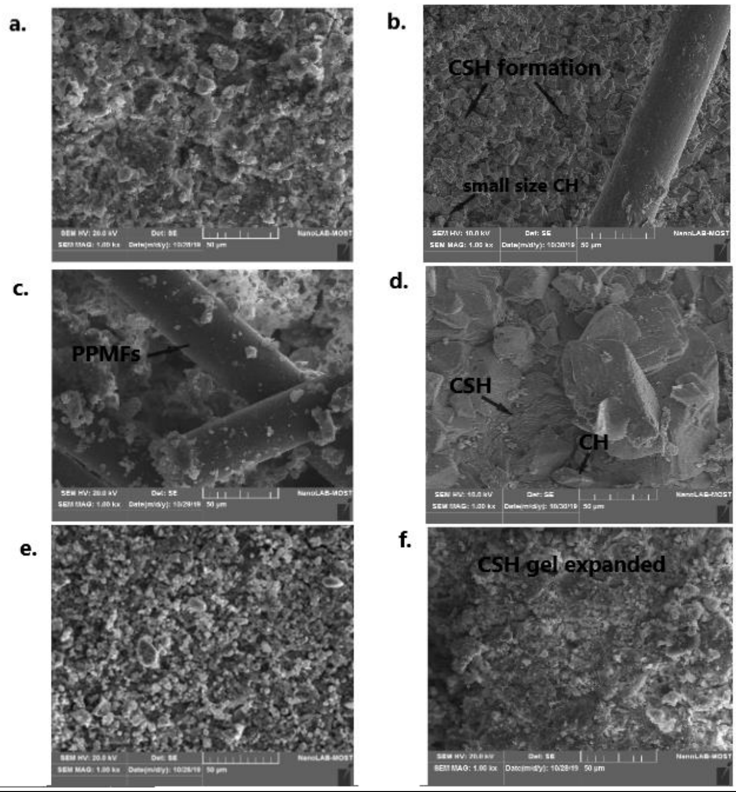


Fig. 13 SEM for Mixed Samples after heals during 28 days: (7 days age on left) (28 days age on right) (a, b 0.5% PPMFs), (c, d 1% PPMFs) and (e, f 1.5% PPMFs)

4. Conclusion:

Experimental results suggest PPMFs significantly reduced workability with %PPMFs increased. The inclusion of PPMFs in mass concrete leads to an increase in its compressive strength and flexural strength recovery. However, the required compressive strength greater than 20 MPa can be achieved for contents less than 2%PPMFs. It also improves the physical properties of the mass concrete. PPMFs with 1% significantly improves the sealing of cracks of mass concrete by up to (29- 57)% at 7and 28 days age of the healing period, respectively, which is better than control samples that achieved (18.6-44.3)% at 7and 28 days age of the healing period, respectively. The presence of PPMFs leads to the intensification microstructure of concrete. It acts as a network that limits the size, content, and direction of CH crystals and micro-voids. A 1%PPMFs was considered an environmental and sustainable choice for building applications.

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