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Contents المحتويات

Research Papers in English

الأوراق البحثية باللغة العربية

INFLUENCE OF POLYPROPYLENE FIBER ON PLASTIC SHRINKAGE CRACKS OF CONCRETE

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الملخص

تشققات الإنكماش اللدن تسرع من عملية تغلغل المواد الضارة داخل الخرسانة وبالتالي فان العمر الخدمي للمنشآت الخرسانية المسلحة في هذه الحالة يكون قصير. أحد الطرق الفعالة للتقليل من التشققات في الخرسانة هو التسليح بالألياف. الهدف الرئيسي من هذه الدراسة المعملية هو للتحقق من تأثير إضافة ألياف البولي بروبلين (0، 0.01، 0.025، 0.1 % من حجم الخرسانة) على سلوك تشققات الإنكماش اللدن خلال الساعات الاولي من خلط الخرسانة. حيث تم دراسة المساحة الكلية وأقصى عرض والطول الكلي لتشققات الإنكماش اللدن للخرسانة المحتوية على ألياف البولي بروبلين ومقارنة النتائج مع خرسانة مرجعية (غير محتوية على ألياف). بالإضافة إلى ذلك تم دراسة الهبوط، الكثافة الرطبة، نضح الماء، مقاومة الضغط، مقاومة الشد الإنشطاري للخرسانة. أشارت نتائج الإختبارات إلى انخفاض ملحوظ في المساحة الكلية وأقصى عرض والطول الكلي لتشققات الانكماش اللدن للخرسانة المحتوية على ألياف البولي بروبلين. محتوى 0.1 % من الألياف نتج عنه انخفاض بمقدار 90، 94، 91% في الطول الكلي، المساحة الكلية واقصى عرض لتشققات الانكماش اللدن على التوالي مقارنة بالخرسانة غير المحتويه على الألياف. وضحت النتائج ايضاً ان إضافة الياف البولي بروبلين الى الخرسانة يؤدي الى زيادة قليلة في مقاومة الضغط ولكن تأثيره يكون ملحوظ في تحسين مقاومة الشد الانشطاري للخرسانة.

ABSTRACT

Plastic shrinkage cracks rapid the ingress of harmful materials into the concrete interior and hence reduce the service life of concrete structures. One of the effective methods to reduce cracks in concrete is by using fiber reinforcement. The main objective of this experimental study was to investigate the effect of polypropylene fiber (0, 0.01, 0.025, and 0.1% by volume of concrete) on the behaviour of plastic shrinkage cracks during the first few hours after mixing of concrete. Total plastic shrinkage crack length, total plastic shrinkage crack area and maximum plastic shrinkage crack width of polypropylene fiber reinforced concrete (PFRC) mixes were investigated and compared with control concrete (without fiber). Properties such as, slump, wet density, water bleeding, compressive strength and split tensile strength were also investigated for fresh and hardened concrete. The test results indicated that the total plastic shrinkage crack length, total plastic shrinkage crack area and maximum plastic shrinkage crack width are significantly reduced with the addition of polypropylene fibers. Fiber content of 0.1% resulted in a 91, 94 and 90% reduction in total crack length, total crack area and maximum crack width, respectively compared to concrete without fiber. The results also showed that the addition of polypropylene fibers leads to a slight increase in compressive strength. However, it causes a considerable improvement in split tensile strength of concrete.

KEYWORDS: Concrete; Plastic Shrinkage Cracks; Polypropylene Fibers; Compression; Strength; Split Tensile Strength.

INTRODUCTION

Fiber reinforced concrete is defined as "concrete made with hydraulic cement, containing fine or fine and coarse aggregate and discontinuous discrete fibers that may also contain pozzolans and additives" [1]. The introduction of polypropylene fibers into concrete mix has no clear effect on compressive strength. Studies by Ramezanianpour et al. [2], Aire et al. [3], Islam and Gupta [4] and Sryh [5] showed reduction in compressive strength with addition of fibers, whereas slight improvement in concrete compressive strength were observed by Li et al.[6], Ede and Ige [7], Elzaroug et al.[8] and Elzaroug and Ebrahim [9]. On the other hand, it has proved to greatly enhance the tensile and flexural strengths of concrete [6-9]. The variation in concrete strengths were reported [10,11] to depend mainly on the percentage of polypropylene fiber included in concrete mix. Study by Archana et al. [10] showed that concrete strength increases with increasing the percentage of polypropylene fiber from 0 to 0.8, while the strength started to decrease when fiber exceeded 0.8%. According to Mashrei et al.[11], reduction in concrete strength was observed when fiber percentage approached to 0.3.

Concrete shrinks when it is subjected to a drying environment. If concrete is constrained from shrinkage, tensile stresses develop and concrete may crack. Shrinkage cracking is one of the most common causes of cracking in concrete walls, slabs, and pavements. Plastic shrinkage cracks facilitate the ingress of harmful agents into the concrete and hence reduce the service life of concrete structures [12]. Fibers have been proved to inhibit crack propagation and reduce crack widths [13-14].

Many investigations have been carried out to document the influence of polypropylene fibers on plastic shrinkage cracking [3,15-21]. Soroushian et al. [15] investigated the effects of collated fibrillated polypropylene fibers on the plastic shrinkage cracking using concrete slabs. The authors concluded that at fiber volume of 0.1%, the total plastic shrinkage crack area and maximum crack width were reduced. It was also concluded that the total plastic shrinkage crack areas were less than those with 13 mm fibers only at 0.1 and 0.2% fiber volume, but not at 0.05% fiber volume. Fibers with 19 mm were found to have 13, 57, and 55% less crack areas than 13 mm fibers at 0.05, 0.1, and 0.2% fiber volume, respectively. The maximum crack widths with 19 mm fibers were 47, 33, and 36% less than those for 0.05, 0.1, and 0.2% fiber volume, respectively.

Naaman et al.[19] studied the plastic shrinkage cracking by using prismatic concrete specimens. Volume fractions ranged from 0.05 to 0.4% of different types of fiber (polypropylene, polyethylene, carbon and polyvinyl acetate) was used. The study showed that the volume fraction and fiber diameter were most effective in controlling plastic shrinkage cracking. The study also showed that at fiber volume of 0.2%, most fibers with less than 0.04 mm diameter reduced plastic shrinkage of concrete by 10% compared to concrete without fiber.

Banthia and Gupta [20] investigated the effect of polypropylene fiber diameter, fiber length and geometry on the plastic shrinkage in concrete. Three types of monofilament and one type of fibrillated polypropylene fibers were used. Different fiber volume fractions of 0.1, 0.2, and 0.3% were used. It was concluded that the longer fiber is more effective in reducing crack area, maximum crack width and number of cracks. Finer fibers were more effective than coarser ones, as they have larger surface area.

Eren and Marar [22] investigated the effect of fiber volume and aspect ratio of hooked steel fibers on plastic shrinkage cracking. Two different compressive strength levels namely 56 and 73MPa were studied. Three different volumes (0.5, 1.0 and 1.5%)

of three different aspect ratios (L/D = 0.55, 0.65 and 0.80) were used. The lengths (L) and diameters (D) of used fibers were 30, 60, 60 mm and 0.55, 0.9, 0.75 mm, respectively. The study showed that steel fibers can significantly reduce plastic shrinkage cracking behavior of concretes. The study also showed that there is a critical fiber volume content of fibers to reduce the total crack length for both concrete series and there is a linear relationship between total plastic shrinkage crack area and volume percentage of steel fibers.

In this study, concrete plates having dimensions of 50x450x450 mm were used for assessing plastic shrinkage cracking. Maximum crack width, total crack area and total crack length were investigated. Fresh and hardened properties of polypropylene fiber reinforced concrete, such as splitting tension strength, compression strength, slump, wet density and water bleeding were also studied. Three different volume percentages (0.01, 0.025, and 0.1% by volume of concrete) of polypropylene fibers were used.

EXPERIMENTAL PROGRAM

Materials properties

In this study, polypropylene fiber reinforced concrete mixes were made of Ordinary Portland cement obtained from Alfataih Factory (Darna-LIBYA), complying with BS 12: 1996. Physical properties and chemical analysis of the cement used are given in Table (1).

Crushed limestone coarse aggregates with maximum size of 20 mm were used for production of concrete mixes. Some of the physical and mechanical properties of the aggregates used in this investigation are given in Table (2). Aggregate properties were measured in accordance with BS 812: Part 2: 1995, BS 812: Part 110: 1990 and BS 812: Part 112: 1990.

Natural sand with an apparent specific gravity of 2.69 and absorption of 0.42% was used. The sieve analysis results of the sand and coarse aggregates used in the concrete mixtures are given in Table (3).

Polypropylene fibers Figure (1) having 18 mm length were used in this study. Three different fiber percentages were added to concrete mixtures at 0.01, 0.025, and 0.1% by volume of concrete (i.e. 0.091, 0.227 and 0.910 kg/m^3).

Table 1: Physical and chemical properties of cement

Chemical Composition (%)		Physical properties	
SiO_2	20.9	Fineness-Blaine (cm^2/gr)	3093
CaO	63.2	Setting Time (minute) ;	
Fe_2O_3	3.03	Initial	129
Al_2O_3	5.39	Final	164
MgO	1.35	Specific weight	3.07
SO_3	2.4	Compressive strength (MPa);	
Loss of ignition	2.6	3days	24.1
Alkalies	0.88	28days	44.8

Table 2: Physical and mechanical properties of coarse aggregate

Property	
Apparent specific gravity	2.66
Absorption (%)	1.53
Impact value (% Fines)	16
Crushing value (% Fines)	31

Table 3: Sieve analysis of used sand and coarse aggregate

Sieve (mm)		20	14	10	5	2.36	1.18	0.6	0.3	0.15
Passing (%)	Coarse aggregate	99.3	79.5	50.8	1.5	0	-	-	-	-
	Sand	-	-	-	100	99.97	99.47	79.56	25	1.22

Figure 1: Used polypropylene fiber

Mixture proportions and mixing procedure

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method). To achieve the mix design and for target compressive strength equal to 54 MPa, concrete mixture with medium workability and cement content of 550 kg/m^3 were used. Because shrinkage increases with increasing cement content, high cement content of 550 kg/m^3 was used. Proportioning of concrete mixtures is shown in Table (4). All mixtures were mixed in a laboratory pan mixer with a capacity of 56 liters. The mix ingredients placed in the mixer was in the following order; half of the water, fibers, dry aggregates and cement. The combination was mixed for 30 seconds. Then, the rest of water was added gradually in 15 seconds and the mixing continued for 2 minutes and 30 seconds. After mixing, the molds were filled with the four different types of concrete and properly compacted by means of a vibrating table. The top surface was leveled and finished by trowel.

Table 4: Proportioning of concrete mixes (kg/m^3)

Mix	Fiber (%)	Kg/m^3				
		Cement	Fiber	Water	Sand	Coarse Aggregate
HF-0	0	550	0	239.25	499	1164
HF-0.01	0.01	550	0.091	239.25	499	1164
HF-0.025	0.025	550	0.227	239.25	499	1164
HF-0.1	0.1	550	0.910	239.25	499	1164

Curing of test specimens

After casting, the specimens were covered with polyethylene sheet and left for 24 hours in the mould at 20±2°C (laboratory temperature). After 24 hours, concrete specimens were removed from the mould and kept in water curing for 28 days at 20°C.

Experiments on fresh concrete

The workability of freshly mixed concrete was assessed by using slump test according to BS1881: Part 102:1983. The fresh unit weight of concrete was measured in accordance with BS 1881: Part 107:1983. Bleeding of concrete mixtures was also measured in accordance with ASTM C 232 - 92.

Compressive and split tensile strength tests

Compressive strength test was performed on 100 mm cubes according to BS 1881: Part 116:1983. The size of standard cylinder mould used for splitting tensile strength was 100 × 200 mm and the test performed according to BS1881:Part 117:1983. For each test three specimens were tested for 28 days of casting. All the specimens were compacted in molds by means of a vibrating table.

Plastic shrinkage cracking test procedure

In this study, the test procedure was similar to the procedure followed by Eren and Marar [22] and Abdalkader [23]. Concrete slabs with 50×450×450 mm Figure (2) were exposed to identical finishing processes and environmental conditions (temperature, humidity, and wind velocity). The temperature during testing was 35 °C and the relative humidity was 40 ± 5 percent, while the wind speed was kept constant (15 km/h) by utilizing fans. The fans were started 20 minutes after the addition of water to the mixer for all test slabs. A 140 mm-diameter metal mold located next to slab specimens to measure the water evaporation rate from the fresh concrete surface Figure (2).

The evaporation rate can be determined theoretically from the relative humidity, air temperature, concrete temperature and wind velocity using the nomograph provided by ACI 305R-10 [24]. Cracking is most likely to occur when the environmental conditions give an evaporation rate in excess of 1 $kg/m^2/h$. It is recommended that precautions be taken when the anticipated evaporation rate is likely to exceed 0.5 $kg/m^2/h$.

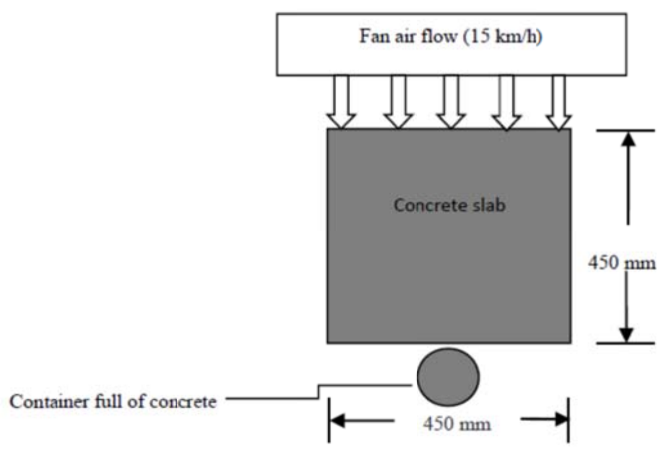

Figure 2: Plan view of plastic shrinkage test arrangement

Shrinkage cracks were measured 5.5 hours after concrete placement. Hand-held microscope and map measurer Figure (3) were used to measure crack width and crack length, respectively. During these measurements, total crack length, maximum crack width, and total crack area were obtained.

The cement content used in this study is relatively high, a quantity usually used to produce high compressive strength concrete. In order to evaluate the effect of fiber level on behaviour of plastic shrinkage cracks and because shrinkage increases with increasing cement content, high cement content of 550 kg/m^3 was used in this study. It should be noted that with such high cement content, drying shrinkage is also expected to increase. Drying shrinkage is mainly caused by the loss of water from the cement paste. When concrete dries, free water loss from the capillaries. As a result, internal relative humidity gradients within the cement paste structure takes place. With time, water molecules are transferred from the large surface area of the calcium silicate hydrates into the empty capillaries and then out of the concrete. In consequence, the cement paste contracts [25].

Map measurer Hand-held microscope

Figure 3: Used hand-held microscope and map measurer

RESULTS AND DISCUSSIONS

Fresh mix properties

The result of slump test is shown in Figure (4). As Figure (4) shows, the slump decreases with the addition of polypropylene fibers, and thus the workability decreases with increasing the polypropylene fibers. This is because increasing the amount of fibers in the mix causes better resistance against compaction. The lowest slump is obtained in mix HF-0.1 with fiber volume fraction of 0.1% and the reduction is about 30% compared to control concrete (HF-0). Increasing the fiber volume percentage causes no change in the wet density of fresh concrete for all mixes. The wet densities were between 2356 and 2358 kg/m^3.

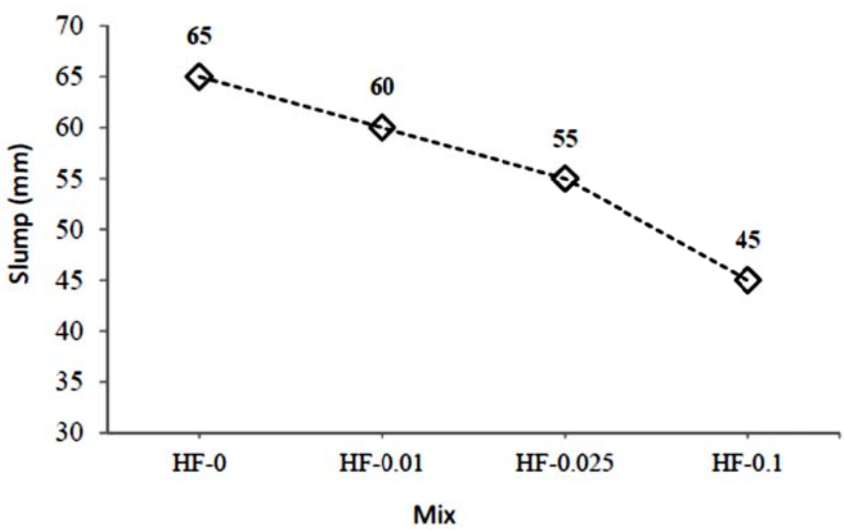

Figure 4: Slump results

Water bleeding

Bleeding test results of concrete mixtures are shown in Figure (5). It can be seen from the graph that there is no significant changes in the amount of water bleeds for all concrete mixtures. The graph also shows low amount of water bleeds for all mixtures, and this may be due to the high cement dose used in producing concrete mixes.

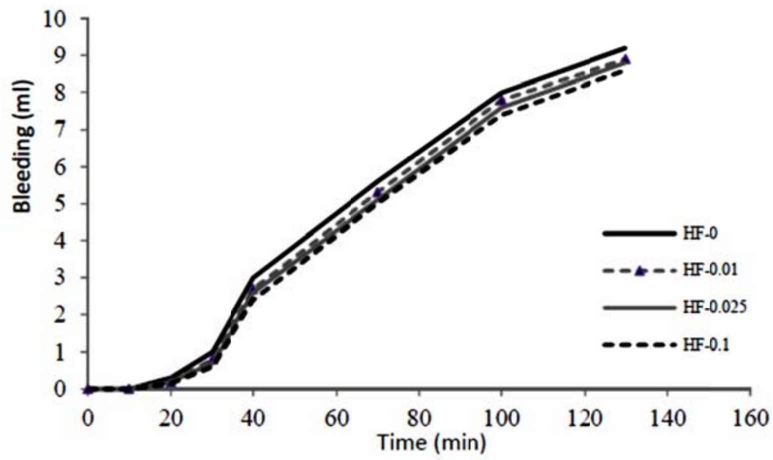

Figure 5: Amount of water bleeding with time

Compressive strength

The values of compressive strength for concrete mixtures ranged from 54.3 N/mm^2 for control concrete (HF-0) to 56.8 N/mm^2 for concrete with 0.1% fiber. A slight increase in compressive strength by about 4.6% was recorded with the addition of 0.1% fiber volume compared to control concrete (HF-0). According to study done by Ede and Ige [7], the use of 0.25% polypropylene fiber in concrete increases the compressive strength of concrete by about 9% and the authors related this to increase the bonding effect between the fiber and the concrete matrix. The authors also state that as the amount of fiber exceeds optimal value, the excess fiber weakens the aggregate interlock thereby reducing the strength of concrete.

Split tensile strength

The effect of fiber fraction on split tensile strength for all concrete mixtures is given in Figure (6). Increasing fiber volume fraction lead to increase split tensile strength compared to control concrete (HF-0), as Figure (6) shows. The maximum increase in concrete split tensile strength is about 46% with fiber volume percentage of 0.1%. Study by Islam and Gupta [4] showed 39% increase in the tensile strength when 0.1% fiber added to concrete. The increase in the ultimate split tensile strength when adding polypropylene fibers could be related to the improvement in the bond of concrete component and thus the resultant arresting growth of cracks.

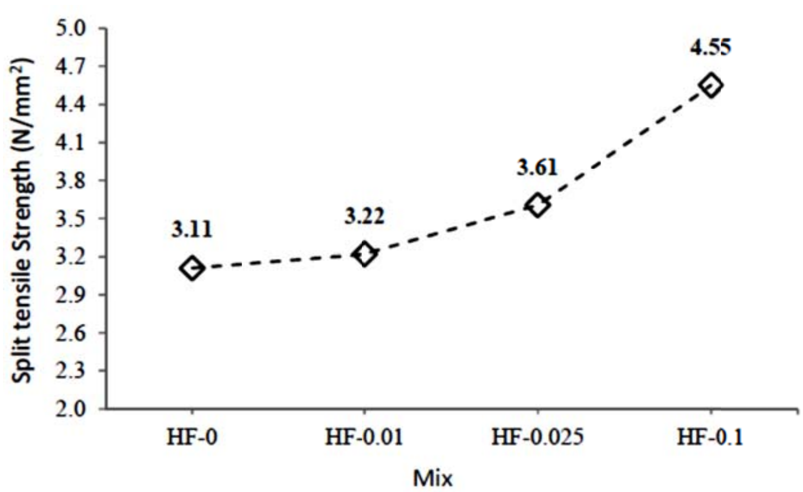

Figure 6: Split tensile strength results

Results of plastic shrinkage cracks

Total crack length

Results of total plastic shrinkage crack length are given in Figure (7). Increasing fiber volume causes a noticeable drop in total crack length Figure (7). A 91 % reduction in total crack length was observed when 0.1% volume fraction of polypropylene fiber used compared to control concrete (HF-0), as Figure (7) demonstrates. This may be due to the increase in tensile strength of concrete incorporating fibers.

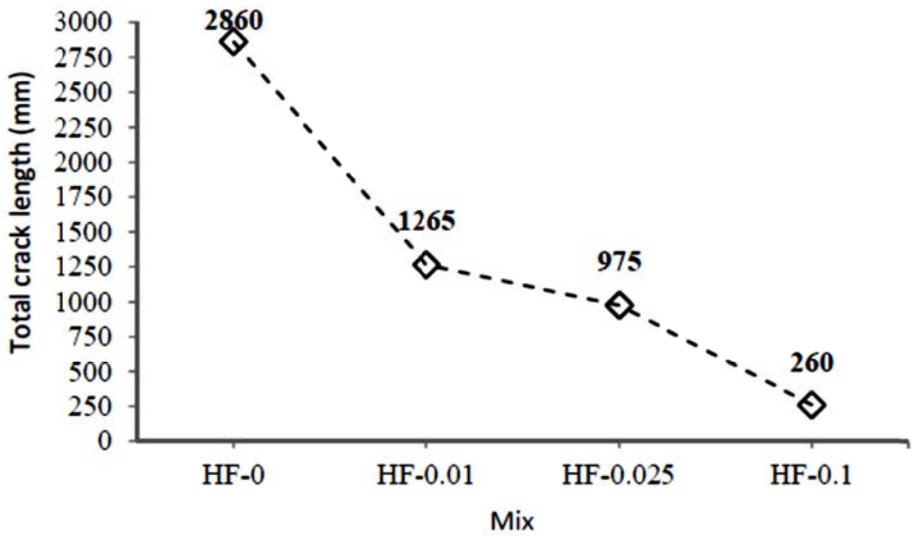

Figure 7: Total plastic shrinkage crack length

Maximum crack width

Figure (8) presents the results of maximum plastic shrinkage crack width. It can be clearly seen from Figure (8) that the addition of polypropylene fiber causes a significant decrease in maximum crack width of concrete compared to control concrete (HF-0). When 0.1% fiber fraction was used, the maximum crack width was reduced by about 90%, compared to control concrete (HF-0). This is due to the enhancement in the bond of concrete component when fiber distributed in the mixture, as Figure (9) illustrates.

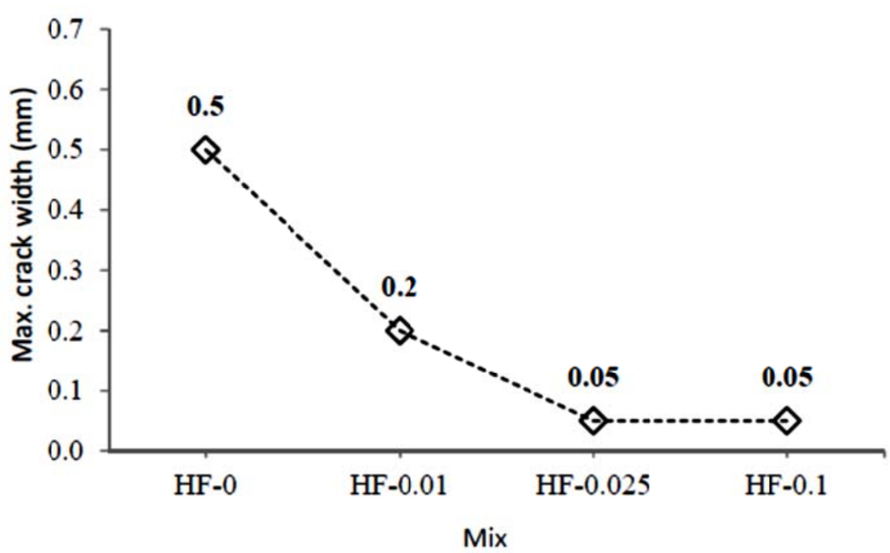

Figure 8: Maximum plastic shrinkage crack width

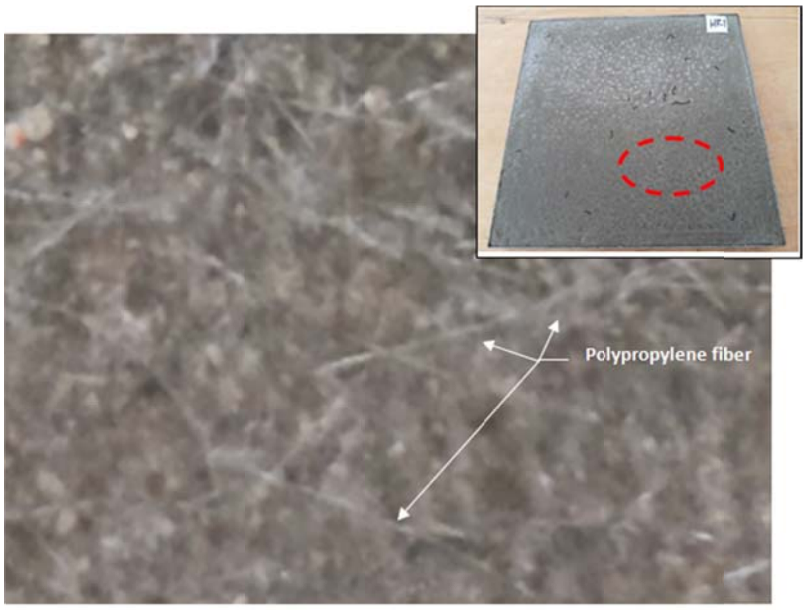

Figure 9: Distribution of fibers on surface of (HF-0.1) concrete slab

Total crack area

Results of total plastic shrinkage crack area are shown in Figure (10). The addition of polypropylene fiber causes a significant decrease in total crack area, as shown in the graph. Fiber content at 0.1% resulted in a 94 % reduction in crack area compared to control concrete without fiber (HF-0).

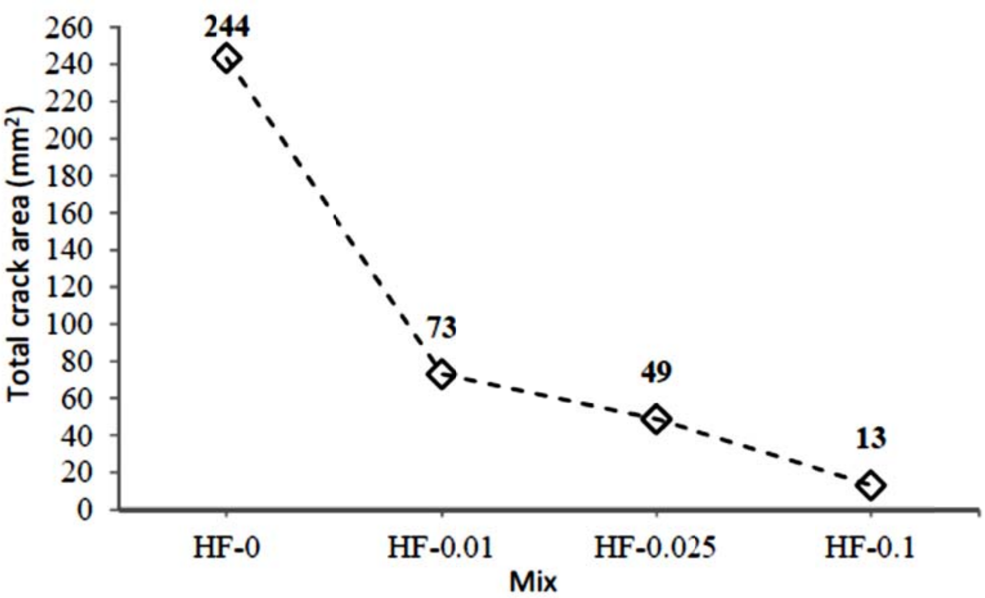

Figure 10: Total plastic shrinkage crack area

According to study by Aire et al. [3], the inclusion of 0.1% polypropylene fibers caused a 60% average reduction in crack area. Polypropylene fibers with 19 mm length were reported [15] to have 13, 57, and 55% less crack areas than 13 mm fibers at 0.05, 0.1, and 0.2% fiber volume, respectively.

CONCLUSIONS

The following findings can be drawn from the obtained results:

- The slump of concrete mixture decreases with the addition of polypropylene fiber.
- The compressive strength of concrete is slightly increased with the addition of polypropylene fiber. On the other hand, significant enhancement in splitting tensile strength is gained with the addition of polypropylene fiber. A 46% increase in split tensile strength was obtained when 0.1 fiber volume was added to concrete compared to control concrete (without fiber). This can be attributed to arresting cracks by fiber addition.
- The maximum crack width, total crack area and total crack length of concrete slab is significantly reduced with the addition of polypropylene fiber. The addition of 0.1% fiber led to a 90 %, % 94 and 91% reduction in maximum crack width, total crack area and total crack length, respectively compared to control concrete. This reduction is possibly related to the decrease in workability as fiber added to concrete mixture.

RECOMMENDATIONS

- In this study, concrete produced with high cement content was studied. Concrete mixtures with different cement contents should be investigated.
- In this investigation, concrete with 54 MPa compressive strength was studied. Different strength levels should be studied.
- Other fiber types could be used in this study.
- In this study, fiber volume fraction of 0.01, 0.025 and 0.1 % were studied. Different volume percentage of polypropylene fibers should be tested.

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REFERENCES

[1] ACI Library, “Fiber reinforced concrete”, Concrete International, 1985; 7(3): 64-65.

[2] Ramezanianpour, A., Esmaeili, M., Ghahari, S. and Najafi, M., “Laboratory study on the effect of polypropylene fiber on durability, and physical and mechanical characteristic of concrete for application in sleepers”. Construction and Building Materials, 2013, 44: 411-418.

[3] Aire, C., Mendoza, C., and Davila, P., “Polypropylene fibers reinforced concrete: optimization on plastic shrinkage cracking”. Proceedings of the Second International Conference on Future Concrete, 2011.

[4] Islam, G. and Gupta, S., “Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete”. International Journal of Sustainable Built Environment, 2016; 5(2): 345-354.

[5] الأمين صالح اسريح، مفتاح محمد اسريح "تأثير إضافة ألياف البولي بروبالين على خواص وديمومة الخرسانة". المجلة الدولية المحكمة للعلوم الهندسية وتقنية المعلومات، 2020، المجلد 6، العدد 2، ص: 57 -63.

[6] Li, X., Zhao, J., Wang, W. & Jiang A., "Effects of polypropylene fiber on plastic shrinkage crack and mechanical properties of concrete". Engineering Materials, 2006; 324-325: 487-490.

[7] Ede, A., and Ige, A., "Optimal polypropylene fiber content for improved compressive and flexural strength of concrete". IOSR Journal of mechanical and Civil Engineering (IOSR-JMCE), 2014; 11(3): 129-135.

[8] عمر رمضان الزروق، احمد جميل ابراهيم، سحر عبدالجواد محمد، عبدالعاطي راف الله سعيد، عيسى امراجع "خواص وسلوك الخرسانة المسلحة الحاوية على ألياف البولي بروبلين" المؤتمر العربي الثاني عشر للهندسة الإنشائية، 2013، جامعة طرابلس –ليبيا.

[9] عمر رمضان الزروق، احمد جميل ابراهيم "خواص الخرسانة الليفية العادية والعالية المقاومة". المجلة الدولية المحكمة للعلوم الهندسية وتقنية المعلومات، 2017، المجلد 4، العدد 1، ص: 6 -11.

[10] Archana, P., Nayak, A., Nayak, S., Vaddar, H. and Magnur, D.,"Study of strength of polypropylene fiber reinforced concrete". International Journal of Engineering Research & Technology (IJERT), 2017; 6 (6): 8-11.

[11] Mashrei, M., Sultan, A. and Mahdi, A., "Effects of polypropylene fibers on compressive and flexural strength of concrete material". International Journal of Civil Engineering and Technology (IJCIET), 2018; 9(11): 2208–2217.

[12] Banthia, N., Azzabi, M., and Pigeon, M. "Restrained shrinkage cracking in fiber reinforced cementitious composites". Materials and Structures, 1993; 26(7): 405-413.

[13] Elzaroug, O., Abdalkader, A. and Abubaker, F., "Cracks control in high strength reinforced concrete beams using steel". Journal of Engineering Research (University of Tripoli, Libya), 2017; (24): 29-38.

[14] Abdalkader, A., Elzaroug, O. and Abubaker, F., "Effect of steel fiber on mechanical properties of normal strength concrete". 14th ASEC conference in Jordan, Jordan University of Science & Technology, 2018.

[15] Soroushian, P., Mirza, F. and Alhozajiny, A., "Plastic shrinkage cracking of polypropylene fiber reinforced concrete". Materials Journal, 1993; 92 (5): 553-560.

[16] Bayasi, Z. and McIntyre, M., "Application of fibrillated polypropylene fibers for restraint of plastic shrinkage cracking in silica fume concrete". Materials Journal, 2002; 99(4): 337-344.

[17] Ma, Y., Tan, M. and Wu, K., "Effect of different geometric polypropylene fibers on plastic shrinkage cracking of cement mortars". Materials and Structures, 2002; 35(3): 165–169.

[18] Najm, H. and Balaguru, P., "Effect of large-diameter polymeric fibers on shrinkage cracking of cement composites". Materials Journal, 2002; 99(4): 345-351.

[19] Naaman, A, Wongtanakitcharoen, T and Hauser, G. "Influence of different fibers on plastic shrinkage cracking of concrete". ACI materials Journal, 2005; 102(1): 49-58.

[20] Banthia, N. and Gupta, R., "Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete". Cement and Concrete Research, 2006; 36(7): 1263-1267.

[21] Kadam, O., Udare, S., Shinde, R., Meshram, M. and Tanpure, M., "A study on shrinkage, cracking and strength of concrete using synthetic fibers".

International Research Journal of Engineering and Technology (IRJET), 2020; 07(09): 2014-2018.
[22] Eren, Ö. And Marar, K., “Effect of steel fibers on plastic shrinkage cracking of normal and high strength concrete”. Materials Research, 2010; 13(2): 135-141.
[23] Abdalkader, A., “Plastic shrinkage cracking of fiber reinforced concrete”. MSc thesis, Eastern Mediterranean University, North Cyprus, 2006.
[24] 305R-10, Guide to Hot Weather Concreting reported by ACI committee 305.
[25] Neville, A., "Properties of Concrete”. Fourth Edition, 2003.