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Effect of Polypropylene Fibers on Thermal and Some Mechanical Properties of No-fines Concrete

Abstract- *This research aims to find the optimum percentage of polypropylene fibers that can be added to no-fines concrete. The fibers added to the (1:5, 1:6, and 1:7 mix proportions) concrete with volumetric percentages of (0.1, 0.2, 0.3, 0.4, and 0.5%), together with suitable amounts of superplasticizer to keep the flow percentage at (65-75%) using constant w/c ratio of 0.4. The results indicated that the optimum volumetric percentage of the added polypropylene fibers is 0.3% which needs small amount of superplasticizer of 0.5% by cement weight, to keep its flow equivalent to the reference mix. This percentage of fibers cause an increase in compressive strength, splitting tensile strength, and modulus of rupture of 22.5, 56.1, and 67.8% respectively when using 1:5 and 1:6 of concrete mixture. But this percentage decrease when using concrete mix proportion of 1:7 to be 8.8, 23.8, and 24% respectively. Also, results indicated that concrete density and thermal conductivity didn't affect significantly by fibers addition.*

Keywords- *no-fines concrete, polypropylene fibers*

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1. Introduction

No-fines concrete is one of lightweight concrete types. It consists of coarse aggregate and cement without any fine aggregates. The advantages of this type of concrete are lower density (1600- 2000 kg/m^3), lower cost due to absence of sand and lower cement content, relatively low drying shrinkage, lower segregation, better thermal insulation characteristic than conventional concrete because of the presence of large voids [1].

One of the most urgent problems in the Iraqi constructional works is the presence of high sulfates in many quarries of sand. In addition to this, there is a need for good thermal insulation building materials due of the hot weather in summer. This can be solve by using no-fines concrete.

This concrete, as any other types of concrete, is brittle and need fibers. Fibers help to improve the ductility performance, tensile strength and eliminate temperature and shrinkage cracks. Therefore in the present work, polypropylene fibers have been chosen to reinforce concrete, due to their low cost and corrosion resistance property. This research aims to find the critical (optimum) volume fraction of polypropylene fibers that can be used with no-fines concrete. Also to investigate the effect of this type of fibers reinforcement on some thermal and mechanical properties of no-fines concrete.

2. Experimental Work

I. Materials

1) Cement

Sulfate resisting Portland cement (Type V) has been used through this investigation. It is produced by United Cement Company (TASLUJA-BAZIAN) in Al-Sulaymaniyah, Iraq. Test results indicated in Tables 1 and 2, show that the cement conformed to the Iraqi specification no. 5/1984 [2].

2) Coarse Aggregate

Normal weight aggregate of maximum size 12 mm was used in this investigation. It was brought from Al-Nebai region. The grading and physical properties of coarse aggregate, shown in Table 3, satisfy the requirements of Iraqi specification No. 45/1984 [3].

3) Fibers

High performance monofilament polypropylene fibresused in this research with the properties listed in Table 4.

Table 1: Cement compounds *

Main Compounds (Brogue's equations)	Percentage
C_3S	48.7
C_2S	24.8
C_3A	6.6
C_4AF	10

* Chemical analysis was conducted by National Center for Construction Laboratories and Research/Baghdad

Table 2: Physical properties of cement

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412-0758/University of Technology-Iraq, Baghdad, Iraq2

Physical properties	Test Results	Limits of Iraqi specification No. 5/1984
Specific surface area (Blaine method), m^2/kg	311	≥ 230
Setting time (Vicate apparatus)		
Initial setting, hr.: min	2:40	≥ 0:45
Final setting, hr.: min	3:50	≤ 10:00
Compressive strength, MPa		
3-day	20.4	≥ 15
7-day	30.2	≥ 23
Soundness (Autoclave method), %	0.38	≤ 0.8

Table 3: Properties of coarse aggregate

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No. 45/1980 for 14 mm single size aggregate
14	100	100
12	100	------
10	92.2	85-100
5	15.3	0-25
2.36	2.1	0-5
Specific gravity	2.69	-------
Sulfate content, %	0.09	≤ 0.1
Absorption, %	0.53	--------

Table 4: Properties of fibers*

property	Polypropylene Fibers
Specific gravity	0.91
Fiber length, mm	12
Fiber Diameter, micron	18
Aspect ratio	667
Water Absorption	Nil
Tensile strength, MPa	(300-400)

*According to the manufacturer

4) Water
Potable water (tap water) from the water-supply network system was used for mixing and curing throughout this work.

5) Admixture (Superplasticizer)
High range water reducing admixture type G, according to ASTM C494 [4], with a trade name Flocrete W52, has been used throughout this work.

II. Concrete Mixtures
The details of mixes used throughout this investigation are given in Table 5.

III. Preparation, casting and curing
The coarse aggregate, and cement, were first mixed dry in a pan mixer of ($0.03m^3$) capacity for a period of 2 min. The superplasticizer was then mixed thoroughly with the mixing water and added to the mixer. Fibers were dispersed by hand in the mixture to achieve a uniform distribution throughout the concrete, which was mixed for a total of 4 min. There were no fibers balling during mixing and placing for all the concrete mixtures. Fresh concrete was cast in steel moulds and compacted by rodding. The specimens were kept in their moulds for 24h. There was less bleeding in the fiber reinforced concrete compared to that of the control concrete. After demolding, concrete specimens were placed in 20±2 °C water until testing. They were removed from water and placed in the laboratory environment, 2 hrs before carrying out the tests. All tests were performed according to relevant specification standards.

3. Results and discussion

I. Flow test
Flow test is a good indication for the concrete cohesion. It is suitable to assess the quality of fresh no-fines concrete that cannot be done by slump test. The consistency was tested by the flow Table test in accordance with ASTM C124-71 [5].
Table 6, shows the effect of polypropylene fibers addition on the flow of no-fines concrete with mix proportions 1:5, 1:6 and 1:7. Results indicate that there is a reduction in flow with increasing the percentage of fiber addition. This reduction in flow comes from its high surface area to volume ratio. Results and visual observation indicate that it is possible to add not more than 0.2% of polypropylene fibers to no-fines concrete, of mixes 1:5 and 1:6, without need to superplasticizer addition to have a homogeneous mix and no appreciable effect on its flow. Results also show that 0.5% and 1% of superplasticizer should be added to no-fines concrete mixes when there is an addition of 0.3% and 0.4-0.5% of fibers addition respectively to the concrete mixes, otherwise the flow of the mixes decrease. Concrete mixture of 1:7cement: gravel, with or without fibers, need 0.5% superplasticizer addition to have the required flow as that for other mixes (1:5 and 1:6).

II. Dry Density
The 28-day dry density of no-fines concrete was measured using the average of three (100 x 200 mm) cylindrical samples, according to the ASTM-C567-10 [6].

The effect of volume fraction of polypropylene fibres on the dry density is shown in Table 6. Results show that there isn't a significant change in the density of no-fines concrete mixes with the addition of polypropylene fibers because of the low percentage of fibers addition. Mix 1:7, with or without fibers, show lower density compared to the other mixes. This might be due to difficulties in its compaction that led to higher voids in the samples.

III. Compressive strength

Compressive strength was measured using 100*100 mm concrete cubes, according to the British Standard Specification BS 1881 part 116:1989 [7]. Test ages of (7, 28, 90 days) were adopted with the average of three samples for each age. Plate (1) shows the no-fines concrete samples.

Table 7, shows the effect of polypropylene fibres on the compressive strength of no-fines concrete with mix proportions 1:5, 1:6, and 1:7. The results illustrate that optimum percentage of fibers added to 1:5 and 1:6 no-fines concrete mixes is 0.3% with superplasticizer content of 0.5% which cause an increase of the reference mixes compressive strength by an average of 22.5%.Then after the strength decrease with increase fibers addition to 0.4 and 0.5%.Results also indicate that the addition of 0.3% polypropylene fibres to no-fines concrete with mix proportion 1:7 cause an increase in its compressive strength of only 8.8%. This might be because fibers did not distribute homogeneously through the mix.

IV. Splitting Tensile strength

The splitting tensile strength test was performed according to ASTM C494-10 [7]. Cylinders of 100*200mm were used and the load was applied continuously up to failure using a digital compression machine of 2000kN capacity (ELE digital testing). The average result of three cylinders was calculated for each age.

Table 8, shows the effect of polypropylene fibres on the splitting tensile strength of no-fines concrete with mix proportions 1:5, 1:6, and 1:7. The results illustrate that optimum percentage of fibers added to no-fines concrete mixes is 0.3% with superplasticizer content of 0.5% which cause an increase of the reference mixes splitting tensile strength by an average of 56.1%. After that the strength decreases with the increase in fiber volumes 0.4 and 0.5%. Results also indicate that the addition of 0.3% polypropylene fibres to no-fines concrete with mix proportion 1:7 causes an increase in its splitting tensile strength by only 23.8%.

V. Modulus of rupture

Prisms with dimensions of (100 * 100 * 400 mm) have been used to measure the modulus of rupture for no-fines concrete, using testing machine shown in plate (2), and following the method of (Third-point-loading) according to the American Standard ASTM C1609-10 [8]. The average of three samples was taken for each age (7, 28, and 90 days), using compression testing machine with capacity of (2000 kN).

The results presented in Table 9, illustrate that the optimum percentage of fibers added to 1:5 and 1:6 no-fines concrete mixes is 0.3% with superplasticizer content of 0.5% which cause an increase of the reference mixes modulus of rupture by an average of 67.8%. After this behavior the strength decreases with the increase in fiber volumes 0.4 and 0.5%. Results also indicate that the addition of 0.3% polypropylene fibres to no-fines concrete with mix proportion 1:7 cause an increase in its modulus of rupture by only 24%.

VI. Thermal Conductivity

A special mould was prepared to produce the required specimen with diameter of (75 mm) and (30 mm) thickness. Four specimens were casted for each mix and tested at 28 days age.

The Hot Disk TPS 500 Thermal Constants Analyser instrument, shown in plate (3), was used for determining the thermal conductivity of concrete samples [10].

The measured thermal conductivity of all mixes of no-fines concrete is shown in Table 10. Thermal conductivity of all studied mixtures has ranged between 0.74 and 0.98 W/m.K at 25° C. The results indicate that there is no significant effect of fiber addition on thermal conductivity of no-fines concrete. This might be due to their low percentage of addition.

4. Conclusions

The following conclusions can be drawn from the results of studying different variables on no-fines concrete:

1) The optimum percentage of fibers that can be added to no-fines concrete mixes is 0.3% by volume. This percentage with addition of 0.5% of superplasticizer to maintain the required flow, give the best required properties of this type of lightweight concrete.

2) Results and visual observation indicate that it is possible to add not more than 0.2% of polypropylene fibers to no-fines concrete, of mixes

1:5 and 1:6, without need to superplasticizer addition to have a homogeneous mix and no appreciable effect on its flow. Results also show that 0.5% and 1% of superplasticizer should be added to no-fines concrete mixes when there is an addition of 0.3% and 0.4-0.5% fibers respectively to the concrete mixes, otherwise the flow of the mixes decrease. Concrete mixture of 1:7cement: gravel, with or without fibers, need 0.5% superplasticizer addition to have the required flow as that for other mixes (1:5 and 1:6).

3) There isn't a significant change in the density of no-fines concrete mixes with the addition of the used percentages of polypropylene fibers. Mix 1:7, with or without fibers, show lower density compared to the other mixes.

4) The optimum percentage of fibers added to 1:5 and 1:6 no-fines concrete mixes is 0.3% with superplasticizer content of 0.5% which causes an increase of the reference mixes compressive strength, splitting tensile strength, and modulus of rupture by an average of 22.5, 56.1, and 67.8% respectively. There after the strength decrease with increase fibers addition to 0.4 and 0.5%. Results also indicate that the addition of 0.3% polypropylene fibres to no-fines concrete with mix proportion 1:7 cause an increase in its compressive strength, splitting tensile strength, and modulus of rupture of only 8.8, 23,8, and 24% respectively.

5) The 28 days age thermal conductivity of all studied no-fines concrete mixtures ranges between 0.74 and 0.98 W/m.K at 25° C. the results indicate that there is no significant effect of fibers addition on thermal conductivity of no-fines concrete.

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Plate 1: No-fines concrete samples used in the test of compressive strength

Plate 2: The apparatus used to conduct the modulus of rupture test

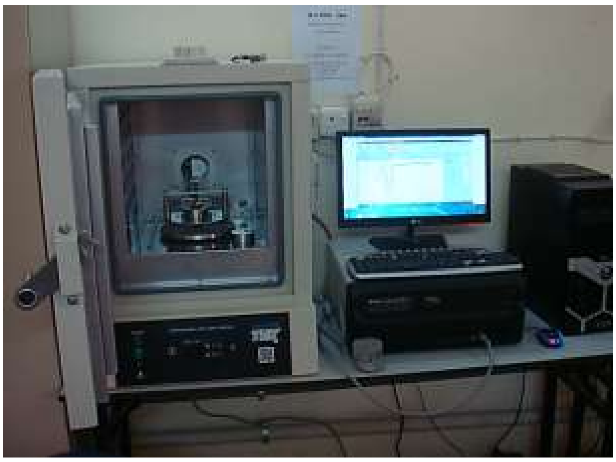

Plate 3: The apparatus used to conduct the thermal conductivity test

Table 5: Mix Proportions used for no-fines mixes with w/c ratio 0.4

Type of mix	Cement: aggregate ratio	fiber by concrete volume (%)	Cement type V (kg)	Gravel (kg)	Super-plasticizer (% by cement weight)
MR1 (reference)		0	300	1500	0
MR1+0.5 S.P		0	300	1500	0.5
MR1+1 S.P		0	300	1500	1
MR1+0.1 P.F		0.1	300	1500	0
MR1+0.2 P.F	1:5	0.2	300	1500	٠
MR1+0.5 S.P+0.3P.F		0.3	300	1500	0.5
MR1+1 S.P+0.4P.F		0.4	300	1500	١
MR1+1 S.P+0.5P.F		0.5	300	1500	١
MR2 (Reference)		0	300	1800	0
MR2+0.5 S.P		0	300	1800	0.5
MR2+1 S.P		0	300	1800	١
MR2+0.1 P.F		0.1	300	1800	0
MR2+0.2 P.F	1:6	0.2	300	1800	0
MR2+0.5 S.P+0.3P.F		0.3	300	1800	0.5
MR2+1 S.P+0.4P.F		0.4	300	1800	1
MR2+1 S.P+0.5P.F		0.5	300	1800	1
MR3 (Reference)	1:7	0	300	2100	0.5
MR3+0.5 S.P+0.3P.F		0.3	300	2100	0.5

Table 6: Flow and dry density of mixes with w/c of 0.4

Type of mix	polypropylene fibers %	Dosage of Superplasticizer L/kg of cement	Flow %	28 days Dry density kg/m^3
MR1 (reference)	----	----	74	1939
MR1+0.1 P.F	0.1	----	73	1928
MR1+0.2 P.F	0.2	----	72	١٩٢١
MR1+0.5S.P+0.3P.F	0.3	0.5	71	١٩١٨
MR1+1S.P+0.4P.F	0.4	1	74.5	١٩١٥
MR1+1S.P+0.5P.F	0.5	1	73.١	١٩١٣
MR2 (reference)	----	----	٧٠	1917
MR2+0.1 P.F	0.1	----	67	1918
MR2+0.2 P.F	0.2	----	66.5	1913
MR2+0.5S.P+0.3P.F	0.3	0.5	73.9	1928
MR2+1 S.P+0.4P.F	0.4	1	٧5,1	١٩٢٦
MR2+1S.P+0.5P.F	0.5	1	70.3	١٩٢٥
MR3 (reference)	----	0.5	72.3	1896
MR3+0.5S.P+0.3P.F	0.3	0.5	68.1	1873

Table 7: Compressive strength of mixes with w/c of 0.4

Type of mix	Dosage of polypropylene fiber kg/m^3	Dosage of Superplasticizer L/kg of cement	Compressive strength MPa		
			7 day	28 day	90 day
MR1 (reference)	----	---	14.8	19.1	20.3
MR1+0.1 P.F	0.1	----	16.25	20.8	21.2
MR1+0.2 P.F	0.2	----	16.7	21.35	22.6
MR1+0.5 S.P+0.3P.F	0.3	0.5	18.3	23.7	25.0
MR1+1 S.P+0.4P.F	0.4	1	8.7	14.2	15.66
MR1+1 S.P+0.5P.F	0.5	1	8.1	13.3	14.4
MR2 (reference)	----	----	٩.١	15.2	17.4
MR2+0.1 P.F	0.1	----	10.2	16.8	18.6
MR2+0.2 P.F	0.2	----	11.12	17.4	18.8
MR2+0.5 S.P+0.3P.F	0.3	0.5	11.4	18.2	20.7
MR2+1 S.P+0.4P.F	0.4	1	5.4	7.34	8.26
MR2+1 S.P+0.5P.F	0.5	1	5.24	6.81	7.46
MR3 (reference)	----	0.5	8.6	14.3	15.47
MR3+0.5 S.P+0.3P.F	0.3	0.5	9.55	15.34	16.74

Table 8: Splitting tensile strength of mixes with w/c of 0.4

Type of mix	Dosage of polypropylene fiber kg/m^3	Dosage of Superplasticizer L/kg of cement	Tensile strength MPa		
			7 day	28 day	90 day
MR1 (reference)	----	---	١.٦٥	1.80	1.90
MR1+0.1 P.F	0.1	----	1.78	2.15	2.31
MR1+0.2 P.F	0.2	----	2.12	2.36	2.49
MR1+0.5 S.P+0.3P.F	0.3	0.5	2.41	2.76	2.93
MR1+1 S.P+0.4P.F	0.4	1	1.22	1.61	1.74
MR1+1 S.P+0.5P.F	0.5	1	1.11	1.53	1.65
MR2 (Reference)	----	----	1.2	1.48	1.62
MR2+0.1 P.F	0.1	----	1.33	1.58	1.74
MR2+0.2 P.F	0.2	----	1.44	1.97	2.00
MR2+0.5 S.P+0.3P.F	0.3	0.5	1.90	2.40	2.60
MR2+1 S.P+0.4P.F	0.4	1	0.71	0.85	0.96
MR2+1 S.P+0.5P.F	0.5	1	0.65	0.78	0.87
MR3 (Reference)	-----	0.5	1.13	1.31	1.37
MR3+0.5 S.P+0.3P.F	0.3	0.5	1.49	1.58	1.63

Table 9: Modulus of rupture of mixes with w/c of 0.4

Type of mix	Dosage of polypropylene fiber kg/m^3	Dosage of Superplasticizer L/kg of cement	Modulus of rupture MPa		
			7 day	28 day	90 day
MR1 (reference)	----	---	٢.١٥	2.45	2.60
MR1+0.1 P.F	0.1	----	2.60	3.44	3.78
MR1+0.2 P.F	0.2	----	3.25	3.94	4.1
MR1+0.5 S.P+0.3P.F	0.3	0.5	3.43	4.2	4.42
MR1+1 S.P+0.4P.F	0.4	1	1.11	2.21	2.57
MR1+1 S.P+0.5P.F	0.5	1	0.97	1.88	1.95
MR2 (Reference)	----	----	1.32	1.6	1.8
MR2+0.1 P.F	0.1	----	1.54	2.24	2.62
MR2+0.2 P.F	0.2	----	1.87	2.50	2.80
MR2+0.5 S.P+0.3P.F	0.3	0.5	2.10	2.73	3.10
MR2+1 S.P+0.4P.F	0.4	1	0.92	0.97	1.2
MR2+1 S.P+0.5P.F	0.5	1	0.85	0.93	1.14
MR3 (Reference)	---	0.5	1.20	1.36	1.51
MR3+0.5 S.P+0.3P.F	0.3	0.5	1.52	1.67	1.85

Table 10: Thermal conductivity of mixes with w/c of 0.4

Type of mix	Dosage of polypropylene fiber kg/m^3	Dosage of Superplasticizer L/kg of cement	28 days age thermal conductivity W/m.K
MR1 (reference)	----	---	٠.81
MR1+0.1 P.F	0.1	----	0.8
MR1+0.2 P.F	0.2	----	0.79
MR1+0.5 S.P+0.3P.F	0.3	0.5	٠.٧٨
MR1+1 S.P+0.4P.F	0.4	1	٠.٩٨
MR1+1 S.P+0.5P.F	0.5	1	٠.٩٤
MR2 (Reference)	----	----	٠.٧٧
MR2+0.1 P.F	0.1	----	0.75
MR2+0.2 P.F	0.2	----	0.74
MR2+0.5 S.P+0.3P.F	0.3	0.5	0.75
MR2+1 S.P+0.4P.F	0.4	1	0.84
MR2+1 S.P+0.5P.F	0.5	1	0.80
MR3 (Reference)	---	0.5	0.81
MR3+0.5 S.P+0.3P.F	0.3	0.5	0.786

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