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INFLUENCE OF POLYPROPYLENE FIBER ON THE BOND STRENGTH BETWEEN STEEL BAR AND CONCRETE

* Sura Amoori Abbas [1], Aseel Abdulazeez Abdulridha [2] and Saba Mohammed Sabih[3]

[1,2,3] Department of Civil Engineering, University of Technology- Iraq, Baghdad, Iraq.

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ABSTRACT: Bonding between reinforcement and concrete play an important parameter in the behavior and strength of reinforced concrete. Many parameters influence the bond between reinforcement and concrete such as concrete cover depth, concrete conditions, overall thickness of the structural element and curing. In the present study, a total of sixty specimens as cube with four different percentages of polypropylene fiber (0, 0.5,1 and 1.5) % is used to evaluate the bond strength and stress-slip relationship. The compressive strength of concrete, rebar diameter, concrete cover, and embedded length of reinforcement are taken into account as variables. The test results show that the ultimate bond strength increases with increasing each of the compressive strength of concrete, concrete cover, polypropylene fiber content and decreasing the nominal diameter of the reinforcing bar. The best percentage that gave the maximum failure load, is 1.5% of polypropylene fiber.

Keywords: Polypropylene fiber, Bond strength, Push-out test, Stress-slip.

1. INTRODUCTION

Concrete which is very weak to resist the tension stress that develops in tension zone of concrete section due to applied foresees. Concrete is a kind of building material with weak tensile strength, which is often crack ridden connected to plastic and hardened states, drying shrinkage, and the like. The cracks generally develop with time and stress to penetrate the concrete, thereby impairing the waterproofing properties and exposing the interior of the concrete to the destructive substances containing moisture, bromine, acid Sulphate, etc. The exposure acts to deteriorate the concrete, with the reinforcing steel corroding. To counteract the crack, a fighting strategy has come into use, which mixes the concrete with the addition of discrete fibers [1]. Cracks play an important role as they change concrete structures into permeable elements and consequently with a high risk of corrosion. Cracks not only reduce the quality of concrete and make it aesthetically unacceptable but also make structures out of service. If these cracks do not exceed a certain width, they are neither harmful to a structure nor to its serviceability. Therefore, it is important to reduce the crack width and this can be achieved by adding polypropylene fibers to concrete. Thus addition of fibers in cement concrete matrix bridges these cracks and restrains them from further opening. In order to achieve more deflection in the beam, additional forces and energies are required to pull out or fracture the fibers. This process, apart from preserving the integrity of concrete, improves the load-carrying capacity of structural member beyond cracking [2].

Al-Zuhairi and Al-Fatlawi [3] explored the bond-slip at the interface between surrounding concrete and steel reinforcement. Plain and deformed steel reinforcement bars were adopted with difference of bar diameter, concrete compressive strength and the development length on bond-slip relation. Experimental tests showed that the bond strength increases with increasing of compressive strength and with decreased of bar diameter and development length. Mashrei et al. [4] investigated effects of polypropylene fibers on compressive and flexural strength of concrete material, the main variables are the percentage of polypropylene fiber, type of concrete mix and presence of steel reinforcement in a prism, the results showed that the flexural and compressive strength of concrete increased by increasing the percentage of polypropylene fiber, while by further increasing up to 0.5% the compressive and flexural strength of concrete started to decrease significantly as compared to the control mix.

Arsalan et al. [5] studied effects of polypropylene fiber content on strength and workability properties of concrete, the proportions of polypropylene fiber were ranging from 0.06% to 2.16% , the results found that the fiber content of the concrete mix increase compressive, splitting, and flexural strengths of the concrete, The strengths increased and reached their maximum value at about 0.36% of polypropylene fiber, The concrete strengths started to decrease beyond the percentage of 0.36%. .It is evident from previous studies that there are no studies on the effect of polypropylene fibers on the bonding behavior between concrete and reinforcing steel. In this study, the effect of polypropylene fibers on the bonding strength between concrete and reinforcing steel will be studied, taking into consideration several variables, namely, percentage of polypropylene fiber, compressive strength of concrete, rebar diameter, concrete cover, and embedded length of rebar.

2. THE MATERIALS

The concrete mix contains Ordinary Portland Cement –type I, coarse aggregate with maximum size of (12.5 mm), fine aggregate, manufactured sand with maximum size of (4.75mm). The chemical and physical properties of Portland cement and aggregates matching the Iraqi Specifications No.5/1984 [6] and No.45/1984 [7]. Fig.1 shows the polypropylene fiber type which adapt with length of (12 mm), diameter of (0.016 mm), density (900 kg/m^3) and tensile strength of (400 MPa). Two different concrete grades as (fc′=30 MPa and fc′=60 MPa) in which the average of three cylinders of 150 mm in diameter and 300 mm in length are considered . Cylinder tests based upon ASTMC39 [8] and the compositions for each mix design are listed in Table 1.

Table 1 Compositions of concrete mix design

Materials	Compressive strength *fc'*=30 (MPa)	Compressive strength *fc'*=60 (MPa)
Cement (kg/m^3)	415.00	470.00
Fine aggregate (kg/m^3)	785.00	620.00
Coarse aggregate (kg/m^3)	925.00	900.00
Water (kg/m^3)	210.00	170.00
W/C	0.51	0.36
Slump (mm)	90.00	95.00
Superplasticizer (Liter/100kg of cement)	---	4.00

Fig.1 Polypropylene fiber

3. EXPERIMENTAL PROGRAM

A total of 60 cubes which are classified in five groups as follows: Group A with compressive strength of concrete was 30 MPa, Group B, designed compressive strength was 60 MPa, Group C, the nominal rebar diameter (D-16 mm), Group D, with concrete cover (C-200) and Group E. The embedded length was (L=100 mm). For each group, the polypropylene fiber content was (0, 0.5, 1 and 1.5%) for group A, B, C, D and E individually. The specimen's details are listed in Table 2.

4. PUSH-OUT TEST

Compression monotonic load was applied by hydraulically testing machine with a capacity of (180 kN) as displacement control test at a rate of 0.5 mm / minute [9]. Fig.2 shows the specimens under test. The conventional reinforcement was pushed from one end of the test specimen to produce the slippage between the reinforcing bar and the concrete. The vertical displacement (slip of the reinforcing bar) was measured at the end of the loaded steel bar by actuator displacement. All specimens are cured up to 28 days. The bond strength is calculated by applying [10]. "Eq. (1)":

$$\tau ult = \frac{p\ ult}{\pi\ D\ Ld} \qquad (1)$$

where: τult: Ultimate bond stress, Pult: Ultimate applied force, D: Diameter of steel bar and Ld: embedded length of reinforcing bar in concrete.

Fig.2 Specimen under test

Table 2 Specimens details

Group No.	Specimen mark	fc' (MPa)	% Polypropylene fiber	Nominal diameter (mm)	Concrete cover (mm)	Embedded length (mm)
Group-A	A-0	30	0.0	12	150	80
	A-0.5	30	0.5	12	150	80
	A-1	30	1.0	12	150	80
	A-1.5	30	1.5	12	150	80
Group-B	B-0	60	0.0	12	150	80
	B-0.5	60	0.5	12	150	80
	B-1	60	1.0	12	150	80
	B-1.5	60	1.5	12	150	80
Group-C	C-0	30	0.0	16	150	80
	C-0.5	30	0.5	16	150	80
	C-1	30	1.0	16	150	80
	C-1.5	30	1.5	16	150	80
Group-D	D-0	30	0.0	12	200	80
	D-0.5	30	0.5	12	200	80
	D-1	30	1.0	12	200	80
	D-1.5	30	1.5	12	200	80
Group-E	E-0	30	0.0	12	150	100
	E-0.5	30	0.5	12	150	100
	E-1	30	1.0	12	150	100
	E-1.5	30	1.5	12	150	100

5. TEST RESULTS AND DISCUSSION AND MODE OF FAILURE

5.1 Effect of Compressive Strength of Concrete, fc' = 30 MPa

Table 3 lists the influence of the polypropylene fibers on the strength capacity, bond strength and slip at failure of each specimen within Group A. The increase in specimen's failure load A-0.5, A-1 and A-1.5 comparing with A-0 is (3.39, 11.31 and 16.74) %. The increase in bond strength is (3.40, 10.88 and 16.33) % respectively.

Test results represent the normal strength concrete (30 MPa), steel bar with diameters of (12 mm), and embedded lengths of (80 mm). Fig.3 represents the full behavior of the bond strength – slip that developed at the interface between steel rebar and surrounding concrete.

The behavior starts as linear up to the specific point for each specimen which rely on the presence of polypropylene fibers that reflects the magnitude of compressive concrete strength and then to increase in bond strength inflection point to the nonlinear behavior.

Nonlinear behavior up to ultimate loads for each specimen is related to the percentage of polypropylene fibers and then drops down is due to failure of specimens. Fig.4 shows the mode of failure for all specimens within Group A. The cracks developed and propagated at the top zone from the rebar location at the center. The amount and cracks distributions depend upon the percentage of polypropylene fibers which is increased in percentage that then gave less cracks.

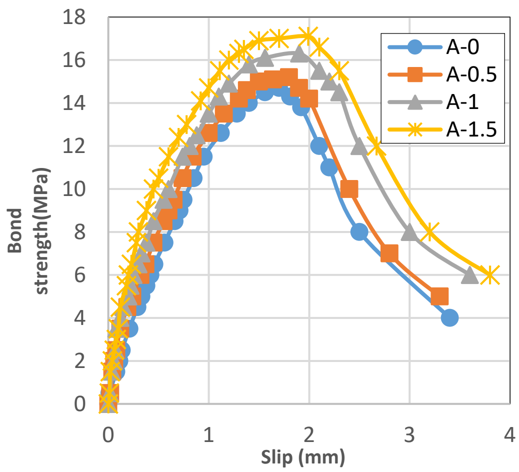

Fig. 3. Bond stress-slip relationship – group A

Fig. 4. Modes of failure - Group A

Table 3 Failure load, bond strength and slips (fc'=30 MPa, D=12mm, cover 150 mm and Ld=80 mm)

Specimen mark	Failure load (kN)	Bond strength (MPa)	Slip at failure (mm)	% Increase of failure load	% Increase of bond strength
A-0	44.2	14.7	1.70	---	---
A-0.5	45.7	15.2	1.80	3.39	3.40
A-1	49.2	16.3	1.90	11.31	10.88
A-1.5	51.6	17.1	1.99	16.74	16.33

5.2 Effect of Compressive Strength of Concrete, fc' = 60 MPa

Table 4 lists the effect of the polypropylene fibers on the strength capacity, bond strength and slip at failure of each specimen within Group B. The increase in specimen's failure load B-0.5, B -1 and B -1.5 comparing with B -0 is (3.26, 9.11 and 15.81) %. The increase in bond strength is (3.11, 9.33 and 15.54) % respectively. Group B represents the normal strength concrete with grade (60 MPa), steel bar with diameters of (12 mm) and embedded lengths of (80 mm). Fig.5 shows the full behavior of the bond strength – slip based on test results that recorded through test. The curve represents the slip that occurs at the circumference of rebar and concrete that confined the reinforcement. Fig.5 describes the bond strength – slip behavior up to failure applied load.

The behavior is the same as concrete grade 30 MPa but differs in strength and slip. It has the same shape as mathematic and nonlinearity behind the inflection points that related to percentage of polypropylene fibers. Mode of failure for Group B is shown in Fig.6.

The cracks started from the location of rebar and propagated toward the edges as the load increments. The cracks intensity and length become less when the polypropylene fibers percentages increased (such as specimens B1 and B1.5).

A comparison between specimens in Group A and B is listed in Table 5. The bond stresses increase when the grade of concrete increase due to higher compressive strength which gave more confinements around the rebar.

Table 4 Failure load, bond strength and slips (fc'=60 MPa, D=12mm, cover 150 mm and Ld=80 mm)

Specimen mark	Failure load (kN)	Bond strength (MPa)	Slip at failure (mm)	% Increase of failure load	% Increase of bond strength
B-0	58.2	19.3	2.6	---	---
B-0.5	60.1	19.9	2.7	3.26	3.11
B-1	63.5	21.1	2.9	9.11	9.33
B-1.5	67.4	22.3	3.0	15.81	15.54

Table 5 Comparison between specimens in group A and B

% Polypropylene fibers	Bond strength-group A (MPa)	Bond strength-group B (MPa)	% Increase of bond strength (A and B) groups
0.0	14.7	19.3	31.29
0.5	15.2	19.9	30.92
1.0	16.3	21.1	29.45
1.5	17.1	22.3	30.41

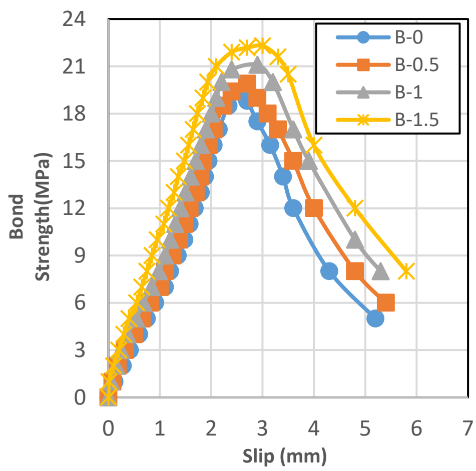

Fig. 5. Bond stress-slip relationship– group B

Fig. 6. Modes of failure - group B

5.3 Effect of Rebar Diameter

Table 6 lists the effect of the rebar diameter with presence of polypropylene fibers on the strength capacity, bond strength and slip at failure of each specimen - Group C. represents the normal strength concrete with grade (30 MPa), steel bar with diameters of (16 mm) and embedded lengths of (80 mm). Fig.7 shows the bond strength – slip at the interface between rebar and concrete due to applied load that produced shear flow and force friction in the revise direction of the applied load. The behavior is the same as for concrete grade 30 MPa and rebar 12 mm in diameter but different in strength and slip. It is the same shape as mathematic and nonlinearity behind the inflection points that related to percentage of rebar diameter. The increase in specimen's failure load is C-0.5, C -1 and C -1.5 comparing with C -0 is (2.04, 5.39 and 10.22%). The increase in bond strength is 2.24, 5.22 and 9.70% respectively. Fig.8 shows the cracks due to the applied compressive load that produced lateral effects and load transfer from rebar to concrete which developed cracks. The failure mode for all specimens is compression which is due to compressive stress.

Comparisons between specimens Group-A (12 mm) rebar diameter with Group - C with a (16 mm), the bond stresses decrease in specimens of Group-C is due to the increase in the contact surface area between the reinforcement and the concrete of Group-C.

Table 6 Failure load, bond strength and slips (fc'=30 MPa, D=16mm, cover 150 mm and Ld=80 mm)

Specimen mark	Load at failure (kN)	Bond strength (MPa)	Slip at failure (mm)	% Increase of failure load	% Increase of bond strength
C-0	53.8	13.4	1.4	---	---
C-0.5	54.9	13.7	1.5	2.04	2.24
C-1	56.7	14.1	1.56	5.39	5.22
C-1.5	59.3	14.7	1.6	10.22	9.70

Table 7 Comparison between specimens in group A and C

% Polypropylene fibers	Bond strength-group A (MPa)	Bond strength-group C (MPa)	% Decrease of bond strength (A and C) groups
0.0	14.7	13.4	8.84
0.5	15.2	13.7	9.87
1.0	16.3	14.1	13.50
1.5	17.1	14.7	14.04

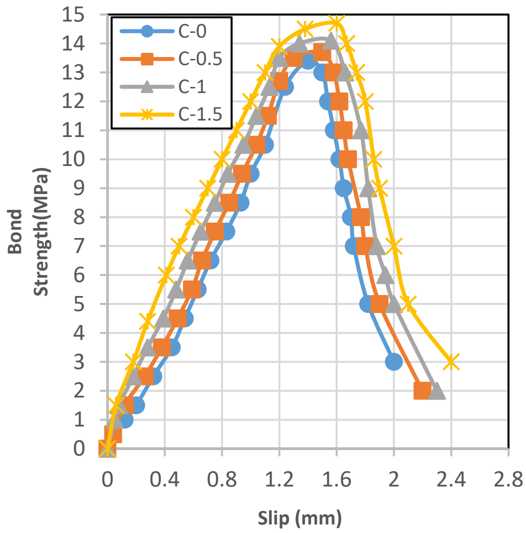

Fig. 7. Bond stress-slip relationship– group C

Fig. 8. Modes of failure - group C

5.4 Effect of Concrete Cover

Polypropylene fibers mixed with four different percentages as (0, 0.5, 1.0 and 1.5%) produced compressive strength concrete (fc′=30 MPa). The rebar diameter is (12 mm) and embedded lengths of (80 mm).

Tables 8 list the failure load, bond strength and slips. The increase in specimen's failure load is D-0.5, D -1 and D -1.5 in comparison with D -0 is (3.35,11.32 and 18.66) %, the increase in bond strength is (3.16, 11.39 and 18.99) % respectively.

Fig.9 demonstrates the bond strength - slips relationship for Group D. The shapes of the curve for all specimens is similar to that the exponential with linear up to the specimens start to cracks and then become nonlinear.

The slop of the curves for all specimens becomes less after the inflection points that related for each specimen. The reduce in slop which is due to increase in slips is also due to the applied load that lead to decrease in stiffness of the specimen. All specimens reach ultimate capacity that rely on the percentage of the Polypropylene fibers and then dropped down are due to failure. Similar trend was observed for the other groups but different in cracks intensity and propagations. Cracks become less when the polypropylene fibers become more which is due to enhance in tension resistance of concrete, Fig.10 shows the modes of failure for all specimens within Group D. Comparisons between the specimens within Group - A and with Group - D are listed in Table 9. Increase in bond strength of Group D is due to increase in the confinement of concrete because increase in concrete cover that lead to increase the concrete volume around the rebar that make decreases in the tensile stresses.

Table 8 Failure load, bond strength and slips (fc'=30 MPa, D=12mm, Ld=80 mm and cover 200 mm)

Specimen mark	Load at failure (kN)	Bond strength (MPa)	Slip at failure (mm)	% Increase of failure load	% Increase of bond strength
D-0	47.7	15.8	1.80	---	---
D-0.5	49.3	16.3	1.86	3.35	3.16
D-1	53.1	17.6	1.98	11.32	11.39
D-1.5	56.6	18.8	2.00	18.66	18.99

Table 9 Comparison between specimens in group A and D

% Polypropylene fibers	Bond strength-group A (MPa)	Bond strength-group D (MPa)	% Increase of bond strength (A and D) groups
0.0	14.7	15.8	7.84
0.5	15.2	16.3	7.24
1.0	16.3	17.6	7.98
1.5	17.1	18.8	9.94

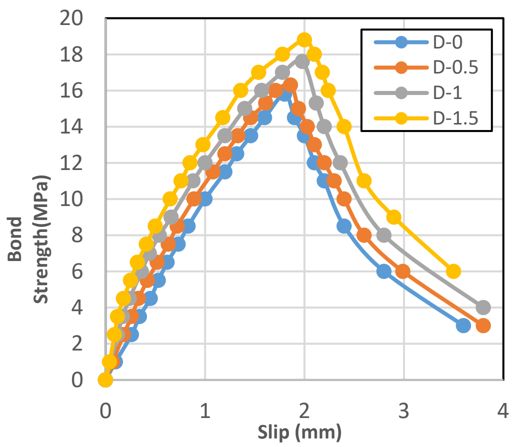

Fig. 9. Bond stress-slip relationship– group D

Fig. 10. Modes of failure - group D

5.5 Effect of Embedded Length

In this group, same amounts of polypropylene fibers and properties of group A except that the embedded length of (100 mm) were adopted. Tables 10 list the failure load, bond strength and slips. The increase in specimen's failure load E-0.5, E -1 and E -1.5 in comparison with E -0 is (5.25, 9.78 and 15.40) %, increase in bond strength is (3.42, 10.27 and 15.75) % respectively.

Fig.11 represents the test results and the full behavior of the bond strength at contact surface and the reinforce bar with the slips that produced which is due to applied loads. Nonlinear behavior of the bond strength with slips after the first crack that formed when the applied load becomes more an elastic load (produce elastic deformation). Fig.12 shows the cracks and the mode of failure as compression failure due to applied increments compressive.

The cracks started from the rebar location at the specimen center (point of applied load) and propagated to the edges of the specimen. The cracks become less when the increased polypropylene fibers which improved the tension resistance of concrete.

Group – A specimens comparing with Group – E, decrease bond strength due to increasing the contact surface area between the reinforcement and concrete in group - E.

Table 10 Failure load, bond strength and slips (fc'=30 MPa, D=12mm, cover 150 mm and Ld=100 mm)

Specimen mark	Load at failure (kN)	Bond strength (MPa)	Slip at failure (mm)	% Increase of failure load	% Increase of bond strength
E-0	55.2	14.6	2.00	---	---
E-0.5	58.1	15.1	2.09	5.25	3.42
E-1	60.6	16.1	2.20	9.78	10.27
E-1.5	63.7	16.9	2.24	15.40	15.75

Table 11 Comparison between specimens in group A and E

% Polypropylene fibers	Bond strength-group A (MPa)	Bond strength-group E (MPa)	% Decrease of bond strength (A and E) groups
0.0	14.7	14.6	0.68
0.5	15.2	15.1	0.66
1.0	16.3	16.1	1.23
1.5	17.1	16.9	1.17

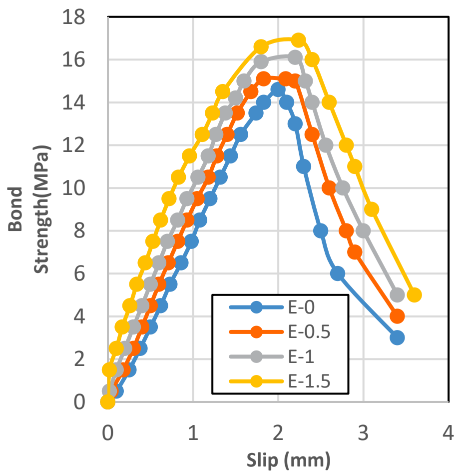

Fig. 11. Bond stress-slip relationship– group E

Fig. 12. Modes of failure - group E

6. CONCLUSION

Followings are the important points which gives the conclusion of this study:

1. In general, adding of polypropylene fibers improved the bonding strength between concrete and steel bar as follows:

- For the specimens with compressive strength of 30 MPa, the bonding strength increased by 3.4%, 10.88% and 16.33% by adding of 0.5%, 1% and 1.5% respectively of polypropylene fibers.
- For the specimens with compressive strength of 60 MPa, the bonding strength increased by 3.11%, 9.33% and 15.54% by adding of 0.5%, 1% and 1.5% respectively of polypropylene fibers.

2. When increasing the rebar diameter from 12mm to 16mm, the bonding strength decreased by a percentage of (8.84, 9.87, 13.5 and 14.04) % for percentages of polypropylene fibers of 0%, 0.5%, 1% and 1.5% respectively.

3. When increasing the concrete cover from 150mm to 200mm, the bonding strength increases by a percentage of (7.84, 7.24, 7.98 and 9.94) % for percentages of polypropylene fibers of 0%, 0.5%, 1% and 1.5% respectively.

4. When increasing the embedded length from 80mm to 100mm, the bonding strength decreased by a percentage of (0.68, 0.66, 1.23 and 1.17) % for percentages of polypropylene fibers of 0%, 0.5%, 1% and 1.5% respectively.

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