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The Behavior of Bond Strength between Rebar and Concrete in Rubberized Concrete

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ABSTRACT

Through an experimental program of eighteen specimens presented in this paper, the bond strength between reinforcing bar and rubberized concrete was produced by adding waste tire rubber instead of natural aggregate. The fine and coarse aggregate was replaced in 0%, 25%, and 50% with the small pieces of a waste tire. Natural aggregate replacement ratio, rebar size, embedded rebar length, the rebar yield stress of rebar, cover, and concrete compressive strength were studied in this investigation. Ultimate bond stress, bond stress-slip response, and failure modes were presented. The experimental results reported that a reduction of 19% in bond strength was noticed in 50% replaced rubberized concrete compared with conventional concrete. The bond strength of rubberized concrete increased when the concrete cover, compressive strength of concrete, and yield stress of rebar were increased. Meanwhile, an increased embedded length of rebar and rebar size decreases the bond strength. The push-out and splitting failure were the failure modes observed in rubberized concrete.

Keywords: rubberized concrete, bond strength, modes of failure

تصرف مقاومة الترابط في الخرسانة ذات المطاط

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من خلال الفحوصات العملية, ثمانية عشر نموذج مقدم في هذا البحث, الترابط بين حديد التسليح والخرسانة ذات المطاط التي تنتج من اضافة اطارات السيارات بدلا عن الحصى العادي. الركام الخشن والناعم يستبدل بنسبة 0%و 25%و 50% مع القطع الصغيرة من الاطارات. نسبة الاستبدال, قطر الحديد, طول الغرز, اجهاد الخضوع للحديد, الغطاء الخرساني, والغطاء الخرساني هي المتغيرات الرئيسية للبحث. علاقة اجهاد الترابط–الازاحة, واشكال الفشل تم عرضها. اجهادات الترابط القصوى, نتائج الفحص بينت ان هنالك نقصان بمقدار 19% في المقاومة القصوى للترابط عند استخدام الخرسانة المستبدل بها الركام بالمطاط بنسبة 50% مقارنة بالخرسانة العادية. مقاومة الترابط للخرسانة ذات المطاط تزداد بزيادة الغطاء الخرساني, مقاومة الانضغاط, اجهاد الخضوع, بينما زيادة طول الغرز, وقطر الحديد يقلل من مقاومة الترابط. التشظي و والسحب هي انواع الفشل التي حصلت في الخرسانة ذات المطاط.

الكلمات الرئيسية: خرسانة ذات المطاط, اجهاد الترابط, اشكال الفشل.

1. INTRODUCTION

Replace part of conventional aggregate with a waste tire rubber is named rubberized concrete, representing an environmentally friendly solution. This kind of concrete has benefits, especially in building subjected to dynamic loading **(Patidar et al., 2018).** The bond between reinforcing bar and rubberized concrete depends on the yield stress of rebar, the cover of concrete, and rebar size **(Emiroğlu et al., 2012).**

A few studies on the bond strength in rubberized concrete have been investigated. Meanwhile, many studies investigated conventional concrete.

(Patidar et al., 2018) replaced the fine and coarse aggregate with pieces of a waste of tires with the percent of 2, 4, 6, 8, and 10% to investigate the bond stress in rubberized concrete. The experimental results showed the bond stress in conventional concrete is less than that of rubberized concrete. **(Emiroğlu et al., 2012)** added waste tires as a fiber to produce rubberized concrete. The bond test result showed that the bond stress decreased when the fiber waste tire increased in rubberized concrete. **(Gesoglu et al., 2015)** tested the fracture and mechanical properties of crump and chips waste tires. Different replacement ratios of 19 specimens were tested. The fracture energy, bond strength, modulus of elasticity, splitting tensile strength, and compressive strength were studied. The results indicated that all the mechanical and fracture properties of rubberized concrete were less than that of conventional concrete. **(Jacintho et al., 2014)** studied the bond strength of 22 specimens through the pull-out test. The replacement ratio of conventional aggregate by waste tires was 10% and 20%. The results proved that the development length needed for rubberized concrete was less than that of conventional concrete. **(Bompa and Elghazouli, 2017)** investigated 54 specimens to investigate the bond stress in rubberized concrete. Also, the design equations in rubberized concrete can be applied up to a 60% replacement ratio.

In summary, it can be noted from the literature that few variables that affect the bond stress in rubberized concrete were studied. Therefore, the objective of the present investigation is to study a wide range of variables: replacement ratio, a cover of concrete, reinforcing bar embedded length, rebar size, and yield stress of steel bar.

2. Experimental Program
2.1 Material and Mix Proportion

In the study by **(Bompa and Elghazouli, 2017),** a mix design of rubberized concrete was adopted herein, according to **Table 1**. The volumetric replacement ratio of fine and coarse aggregate by waste rubber tire was 25% and 50%. The maximum size of waste tire used in rubberized concrete was 10 mm.

Superplasticiser, silica fume, and fly ash were added to increase the workability and strength of concrete.

The reinforcing bar embedded in tested specimens was 12, 16, 22, and 25 mm. The target compressive strength for rubberized concrete, according to **Table 1,** was 24, 30, 35, and 50 MPa. Meanwhile, for conventional concrete was 24 MPa at 28 days.

Table 1: **Mix proportions**

f_c (MPa)	24	24	24	30	35	50
Concrete type	Normal	Rubberized	Rubberized	Rubberized	Rubberized	Rubberized
Replacement ratio (%)	0	25	50	50	50	50
Microsilica	-	41	41	41	41	41
Fly ash	-	41	41	41	41	41
Fine rubber (kg/m3)	0	115	225	225	225	225
Cement (kg/m^3)	365	345	345	345	345	345
Sand (kg/m^3)	765	548	494	554	613	703
Gravel (kg/m^3)	1085	653	605	687	774	905
Admixture	-	7.5	7.5	7.5	7.5	7.5
Water (kg/m^3)	188	147	147	147	147	147
W/C	0.51	0.42	0.42	0.42	0.42	0.42

2.2 Specimen Details

A cubic of 150 x 150 x 150 mm was used to study the bond strength through the push-out test. A reinforcing bar with 5D to 12D anchorage length was used to describe the bonding area. While the other parts of the reinforcing bar had debonding length using a fiber glass pipe, as in **Fig. 1**.

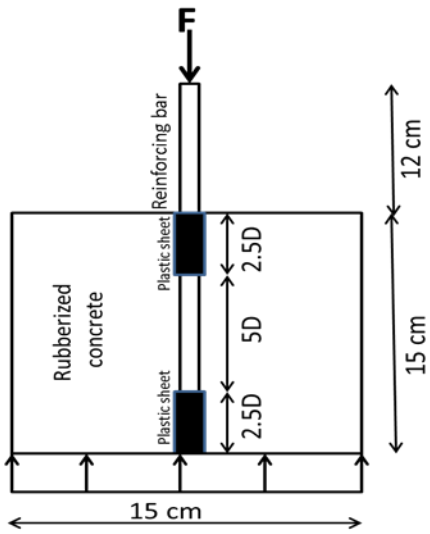

Figure 1: Push-out specimen

2.3 Testing Specimens

Six groups of eighteen specimens were constructed to investigate the bond between rubberized concrete and the reinforcing bar. In the first group, the replacement ratio of conventional aggregate with pieces of tire waste affecting bond stress was studied on specimens (B3-R0%, B2-R25%, and B1-R50%). The second group studied the effect of compressive strength of rubberized concrete on bond stress in specimens (B1-R50%, B4-fc30, B5-fc35 and B6-fc50). The third group studied the rebar size effect on bond strength (B1-R50%, B7-D16, B8-D22, and B9-D25). The fourth group studied the embedded length of reinforcing rebar in rubberized concrete (B1-R50%, B10-Em7D, B11-Em10D and B12-Em12D). The fifth group studied the effect of the yield stress of reinforcing rebar on bond stress (B1-R50, B13-fy325, B14-fy420 and B15-fy625). The sixth group investigated the effect of concrete cover on bond stress (B1-R50%, B16-Co100, B17-Co200 and B18-Co250). **Table 2** presents the details of the specimens.

Table 2: Specimens details

Groups	Specimens	Replacement ratio (%)	f_c (MPa)	Bar diameter (mm)	Embedded length (mm)	Yield stress of rebar	Concrete cover (mm)
Reference	B1-R50%	50	24	12	5D	525	150
One	B2-R25%	25	24	12	5D	525	150
	B3-R0%	0%	24	12	5D	525	150
Two	B4-fc30	50	30	12	5D	525	150

	B5-fc35	50	35	12	5D	525	150
	B6-fc50	50	50	12	5D	525	150
Three	B7-D16	50	24	16	5D	525	150
	B8-D22	50	24	22	5D	525	150
	B9-D25	50	24	25	5D	525	150
Four	B10-Em7D	50	24	12	7D	525	150
	B11-Em10D	50	24	12	10D	525	150
	B12-Em12D	50	24	12	12D	525	150
Five	B13-fy325	50	24	12	5D	325	150
	B14-fy420	50	24	12	5D	420	150
	B15-fy625	50	24	12	5D	625	150
Six	B16-Co100	50	24	12	5D	525	100
	B17-Co200	50	24	12	5D	525	200
	B18-Co250	50	24	12	5D	525	250

2.3 Testing Procedure

The push-out specimens were tested under a 150 kN hydraulic machine. The testing machine pushes the rebar from one side to produce a relative slip between the reinforcing bar and rubberized concrete. Also, shear stresses along the embedded length occurred. The specimens were tested in the displacement control method of 0.3 mm/min. Underneath the specimens, a steel block was placed as support. The slipping and applied loads were recorded for each displacement increment, as in **Fig. 2**.

Figure 2: Test set-up

3. Experimental Results

The bond stresses along the embedded length can be determined as follows:

$$\tau_{ult} = P_{ult} / (\pi D * ld) \quad (1)$$

where: τ_{ult} is the maximum bond strength; P_{ult} is the maximum load; D is the rebar size; ld is the embedded anchorage length.

3.1 Variables Effect on the Bond Strength

The test results are summaries in Table 3 as follows:

- Due to micro-cracks which affect the adhesive force and mechanical interlock, the bond strength of rubberized concrete decreased by 19% when the conventional aggregate was replaced to 50%.
- Increase the compressive strength of rubberized concrete from 24 to 50 MPa, and increase the bond strength by 27.7%. This confirms the concrete compressive strength effect on bond stress.
- The bond strength decreased by 54.2% when the rebar size increased from 12 to 25 mm, this is due to less number of ribs in a bigger size of rebar.
- Increased the anchorage length from 5D to 12D, decreasing the bond stress by 51.1%. This is because a small value of bond stresses is produced in a long anchorage.
- The bond strength increased by 72.1% when the yield stresses of rebar increased from 325 to 625 MPa; this is due to more stresses transferred between the concrete and reinforcing bar.
- The bond strength increased by 3.3% when the concrete cover increased from 100 to 250 mm due to the confinement effect produced by the concrete cover on the reinforcing bar.

Table 3: Ultimate bond strength

Groups	Specimens	Ultimate
Referenc	B1-R50%	9.09
One	B2-R25%	9.94
	B3-R0%	10.81
Two	B4-fc30	9.12
	B5-fc35	9.89
	B6-fc50	11.65
Three	B7-D16	6.81
	B8-D22	4.94
	B9-D25	4.16
Four	B10-Em7D	7.55
	B11-Em10D	4.98
	B12-Em12D	4.44
Five	B13-fy325	6.1
	B14-fy420	7.5
	B15-fy625	10.5
Six	B16-Co100	8.65
	B17-Co200	8.84
	B18-Co250	8.94

3.2 Relations Between Bond Stress and Slip

The bond stress is the ratio between the load over the concrete surface area. Meanwhile, the relative slip between concrete and the reinforcing bar is recorded from the testing machine. In **Fig. 3**, the relation between bond stress and slip response is depicted. In which chemical adhesion is controlled, which is described as a linear ascending line. The second part, is nonlinear behavior till maximum load which represents the mechanical interlock. The last part describes the bond failure, which represents the softening behavior.

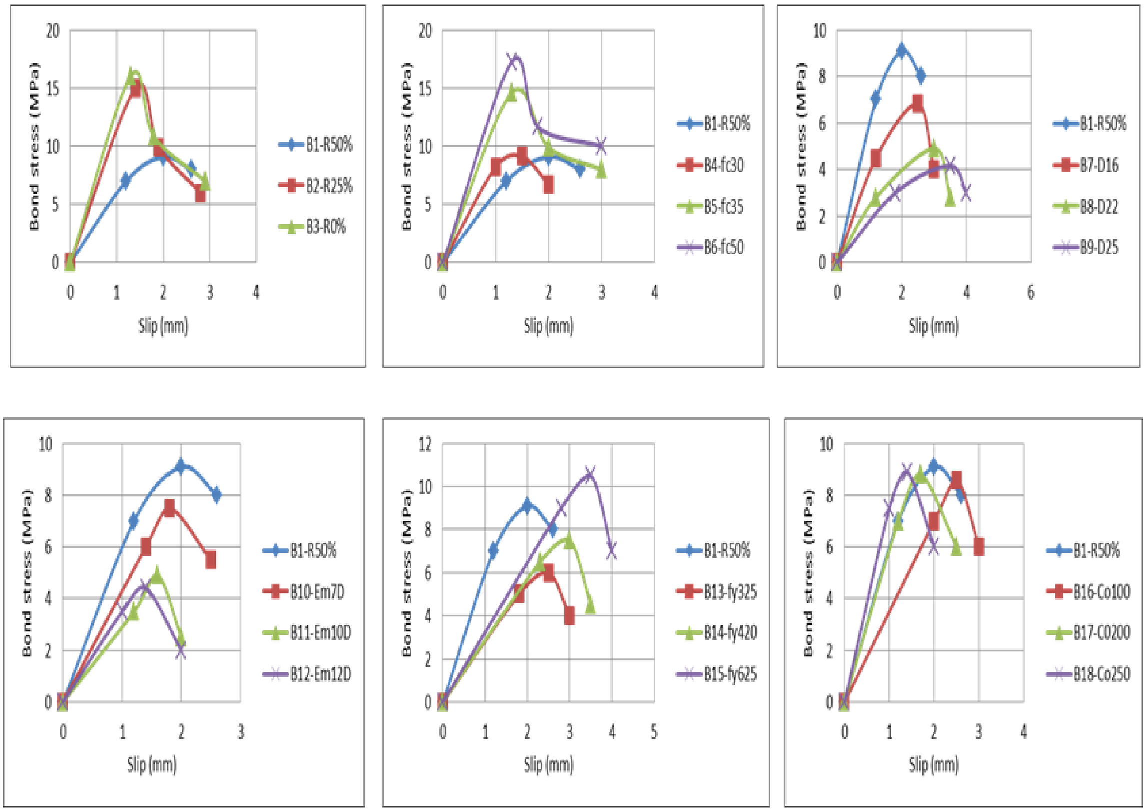

Figure 3: Bond stress-slip behavior

3.3 Modes of Failure

The failure began with the frictional and adhesion failure with a small movement between the concrete and reinforcing bar. Afterward, radial tensile stresses orthogonal to the line of compression forces are produced. If these stresses reach the ultimate tensile strength of rubberized concrete, the circumferences surface cracks happen as splitting failure. When no surface cracks occurred, and the reinforcing bar penetrates through the other side, a push-out failure occurs.
Increasing the concrete cover produced push-out failure; meanwhile, increasing the rebar size, replacement ratio, and concrete compressive strength produced splitting failure, as in **Fig. 4**.

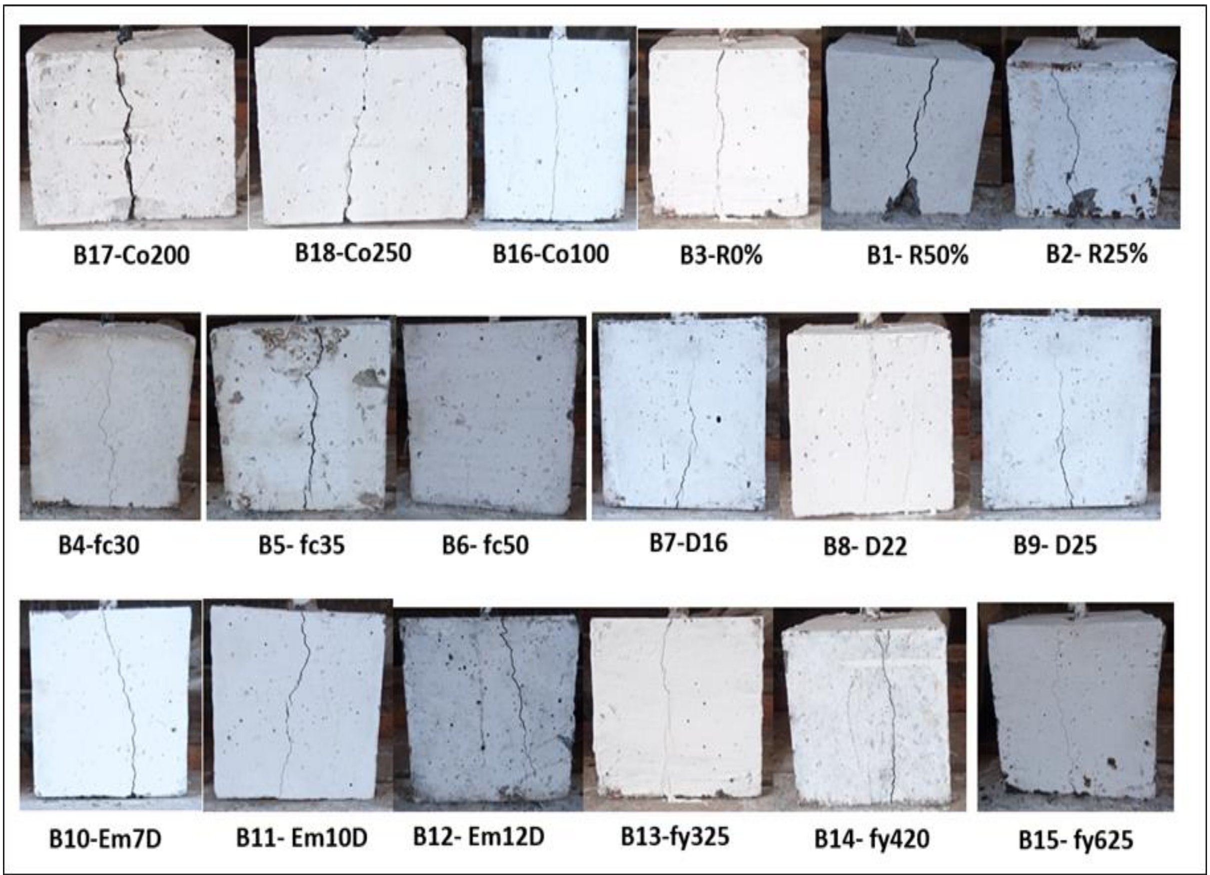

Figure 4: Modes of failure

4. CONCLUSIONS

- The bond strength between reinforcing bar and rubberized concrete is decreased by 19% when the conventional aggregate is replaced by 50% with waste rubber.
- Increase the compressive strength of rubberized concrete from 24 to 50 MPa, which will increase the bond strength by 27.7%.
- The bond strength decreased by 54.2% when the rebar size increased from 12 to 25 mm.
- Increased the anchorage length from 5D to 12D decreases the bond strength by 51.1%.
- The bond strength increased by 72.1% when the yield stresses of the rebar increased from 325 to 625 MPa.
- The bond stress increased by 3.3% when the concrete cover increased from 100 to 250 mm.

- The bond stress-slip behavior is described by the linear part (chemical adhesion) and then the nonlinear part (mechanical interlock or true bond strength). Finally, the last stage represents the softening (bond failure).
- The modes of failure in rubberized concrete are similar to that of conventional concrete: push-out and splitting failure

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