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BOND BEHAVIOR STUDY OF DIFFRENT TYPES OF CONCRETE

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دراسة سلوك الترابط في الانواع المختلفة من الخرسانة

الملخص العربى:

سيؤدي مستقبل البناء إلى زيادة كبيرة في استخدام مواد النفايات المعاد تدويرها للحفاظ على البيئة من الخطر المتزايد لمواد النفايات غير القابلة للاستخدام.في هذا البحث تم خلط خمسة أنواع مختلفة من الخلطات الخرسانية مع المخلفات كبديل بنسبة 20٪ من الركام الخشن اوالناعم ، ثم تم إجراء سلسلة من الاختبارات على عينات من كل نوع ، ثم تمت مقارنة جميع النتائج مع نتائج الخرسانة العادية للتحقق من سلوك التماسك لكل نوع من أنواع الخرسانة. تتمثل الأهداف الرئيسية لهذا البحث في دراسة والتحقق من سلوك التماسك في (الخرسانة العادية ، والخرسانة المصنوعة من ألياف الصلب ، والخرسانة المطاطية المتفتتة ، والخرسانة المعاد تدويرها ، وخرسانة الركام الزجاجي) ، مع حديد التسليح. يقدم البحث البرنامج التجريبي لاختبار العينات عن طريق اختبار الاقتلاع لتقييم سلوك التماسك تحت التحميل الأحادي. أظهرت خرسانة الركام المعاد تدويرها وخرسانة ألياف الحديد المعاد تدويرها نتائج واعدة لقوة التماسك وقوة الانضغاط. كانت خرسانة المخلفات الزجاجية متماثلة تقريبًا مع الخرسانة العادية. أظهرت الخرسانة المطاطية المتفتتة خصائص ضعيفة جدًا لقوة التماسك ولا يمكن اعتبارها مادة يعتمد عليها مثل الخرسانة الإنشائية.

ABSTRACT:

Future of construction will lead to a substantial increase in the use of recycled waste materials for saving the environment from the increasing danger of non-usable waste materials. Five different types of concrete mixes were mixed with waste materials as a replacement by 20% from coarse and fine aggregate, then series of tested were performed on specimens of each mix type, then all results were compared with the results of Normal Concrete to investigate the bond behavior of each mix type of concrete. The main objectives of this research are studying and ascertaining the bond behavior of (normal concrete, steel-fiber concrete, crumbed rubber concrete, recycled aggregate concrete and waste glass aggregate concrete), with steel rebars. The research presents an experimental program of testing pull-out specimens to evaluate the bond behavior under monotonic loading. The recycled aggregate concrete and

recycled steel fibers showed promising results of bond strength and compressive strength. The waste glass aggregate concrete was almost the same with normal concrete. The crumbed rubber concrete showed weak properties of bond strength and can't be considered as a reliable structural material.
KEYWORDS: Normal Concrete, Recycled Steel-Fiber, Crumbed Rubber, Waste Glass, Recycled Concrete, Compressive Strength, Bond strength, Splitting, Pull-Out failure.

I. INTRODUCTION

Recycled waste materials were used in the field of constructions and buildings for saving and being friendly with the environment and to reduce the huge draining of the natural resources of earth, however not all of recycled waste materials can be used in concrete mixes as each material have different properties of bond with concrete composites. That's why it's so important to study the interfacial bond between concrete and reinforcing steel bars as it plays a major role in the performance of reinforced concrete structures. Steel concrete bond enables the forces of tensile to be transferred from the concrete to steel bars. Also, the ability of the concrete element to take these tension forces is dependent on sufficient bond strength between the concrete particles and steel bar which is a very large field. It is well known that concrete can accept a lot of materials to be mixed with it and get result of new type of concrete with new properties and different degrees of bond. Many waste materials were investigated to be used in different concrete mixes such as recycled aggregate concrete, recycled crumbed rubber, recycled waste glass and steel-fiber. The environmental advantages of using waste material as a replacement for aggregate can be investigated in two ways. First way is to remove of a part of the cement from concrete and the other way is to use the useless waste materials in concrete. Due to the volume of concrete consumption around the world, a lot of waste can be used as a replacement for concrete. The consumption of concrete is about (33 billion tons per year) (ISO/TC 071), if 5% of the concrete projects around the world used 10 to 15% of waste material to replace aggregate, in one year a large amount of the waste generated can be reused. Also, if this consumption of concrete continued and extended to 10% of the world's projects, the total waste from past years can be completely consumed by reusing it in concrete in a few years. This will save on consumption of the world's other resources and at the same time, reduce environmental pollution in all over the world. Therefore, the use of waste material as a substitute for aggregate is beneficial for waste materials disposal, as it is impossible to use only waste material instead of aggregate in construction.

2. EXPERIMENTAL WORK

The experimental program consisted of testing 60 specimens divided in to 30 compressive strength specimens and testing 30 pull-out specimens for (Normal Concrete, Steel-Fiber Concrete, Rubberized Concrete, Recycled Aggregate Concrete, and Waste Glass Aggregate Concrete) and the control mix will be the normal concrete to compare the results with it. The considered parameters in this study are stated as following:

a) Concrete type (Normal Concrete, Steel-Fiber Concrete, Rubberized Concrete, Recycled Aggregate Concrete, and Waste Glass Aggregate Concrete).
b) Bar diameter through using Ø 12, Ø 16 mm deformed reinforcement bars.

2.1 Materials

a) Fine Aggregate (Sand)

Clean and round fine aggregate was used. The sand was washed and dried in open area before using. The sand grading was maintained by using sieves according to ECP (Egyptian Code of Practice No 203, 2001). Very fine material was excluded from the mixture by using fine sieves. The properties of fine aggregates are given in Table1.

b) Coarse Aggregate (Gravel)

Round, well-graded and clean gravel was used in the mixture with two sizes of (10and 20) mm. The gravel was washed using potable water to ensure the removal of dust or impurities that might exist. The properties of coarse aggregates are given in Table1.

c) Cement

Ordinary Portland cement was used throughout the program for making concrete. The fineness degree, Initial and final setting times and the mortar compressive strength were measured according to (ESS 756/2007). The properties of cement are mentioned in Table 2.

d) Water

Potable water was used in the mixes. Chemical analysis test of the water showed that it was suitable for concrete.

e) Recycled aggregate

Recycled concrete aggregate (crushed concrete cubes) were used in this research from the laboratory of concrete from cubes that its compressive strength were known, and with replacement by 20% from natural aggregate. The properties of Recycled aggregates are given in Table1.

f) Waste glass aggregate

Most of the raw glass materials used in this study were clear flat glass. The first step in preparing the glass aggregate was the crushing process, which was carried out using crushing machine. The properties of Waste glass are given in Table3.

g) Recycled crumbed rubber

For the rubberized concrete mixes, fine aggregate were replaced by a blend of rubber particles produced from the recycling of end-of-life tires. Rubber aggregates with dimensions up to 10 mm, were produced from car tire recycling, whilst larger rubber particles up to 20 mm were produced from truck or bus tire recycling, with typically higher density than car tire particles.

h) Recycled steel-fiber

For the steel-fiber concrete mixes, the steel-fibers were brought from a local factory of recycling waste tires, then it was used as mechanical admixture for ordinary concrete by adding 900 grams fiber to every 1-meter cube of concrete.

i) Reinforcement Steel

The high tensile steel deformed rebars of grade 400/600 having minimum proof strength of 400 MPa and ultimate tensile strength of 600 MPa were used for bar sizes 12mm and 16 mm diameter deformed bars.

Property	Fine aggregate (Sand)	Coarse aggregate (Gravel)	Recycled aggregate
Water absorption (%)	1.19	0.74	2.72
Fineness modulus	2.83	6.98	7.34
Bulk density (kg/m3)	1.59	1.78	1.35
Specific gravity	2.62	2.76	4.72

Table 1: Properties of Aggregate.

% of Retained on Sieve No. 170		4.7
Initial setting times (min)		96
Final setting times (min)		254
Mortar compressive strength (MPa)	3 days	19.55
	7 days	29.14

Table 2: Properties of Cement.

Specific gravity	2.50
Density (Kg/m^3)	1680
Finesse modulus	2.99
Absorption	0.4
Color	Light gray

Table 3: Properties of waste glass.

2.2 Specimen Preparation

The Present study includes 60 specimens, divided into five groups each group includes 12 specimens. The first group of specimens represents the Normal concrete mix was identified as (G1). The second group represents the Recycled glass aggregate concrete mix was identified as (G2), The third group represents the Crumbed Rubber aggregate concrete mix was identified as (G3). The fourth group represents the Steel-fiber concrete mix was identified as (G4). The fifth group represents the Recycled aggregate concrete was identified as (G5). Each group has three cubes for compressive strength test after 7 days and three after 28 days. Also, there are three cubes with 12mm steel bars for pull-out test after 28 days and another three cubes with 16mm steel bars for pull-out test after 28 days. The variables tested were the bar diameter (10, 16) The pullout test uses a 150×150×150 mm standard pullout as shown in Figure (1). The organization of specimens and tests is showed in table (4).

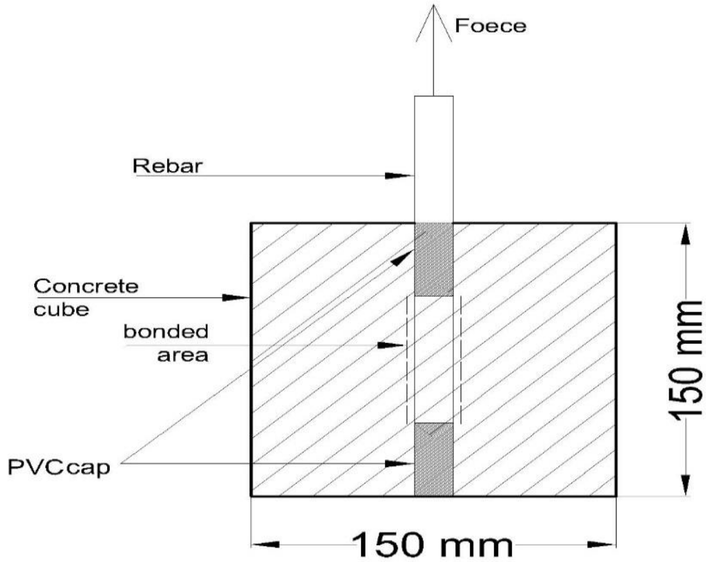

Figure (1): Details of reinforcement of Cubes for pull – out testing.

Concrete mix	**Group**	**Compressive strength**		**Pull-out**	
		7days	**28 days**	**Ø12 mm**	**Ø16 mm**
Normal concrete	G1	3	3	3	3
Waste glass aggregate	G2	3	3	3	3
Rubber aggregate	G3	3	3	3	3
Steel-fiber concrete	G4	3	3	3	3
Recycled aggregate	G5	3	3	3	3
Total		30		30	

Table (4) Test matrix of experimental program.

2.2.1 Concrete mixes

Five concrete mixes were used for the specimens, a normal concrete mix were modified to obtain the rest of other four mixes by replacing coarse or fine aggregate in order to standardize all of concrete mixes components, except in steel-fiber mix the fibers were added to the mix as a mechanical additive material. The mix proportions for all types are shown in Table5.

Concrete mix	Cement	Coarse aggregate	Fine Aggregate	Replace %	Super plasticizer	Water	W/C
NC				0			`
SFC				0			
RC	350Kg	1200Kg	600Kg	20% from coarse agg.	1.8/100 Kg cement	195 L	0.55
WGC				20% from fine agg.			
RAC				20% from coarse agg.			

Table (5): details of mix properties for all five mixes.

Where

NC: Normal Concrete, SFC: Steel-Fiber Concrete, RC: Rubberized concrete.

WGC: Waste Glass aggregate concrete, RAC: Recycled Aggregate Concrete.

3. TEST PERFORMED

In this study there were 60 cubes tested and analyzed for finding the effect of compressive and bond strength of the five concrete mixes. For determining these effects following test were performed.

3.1. Compressive strength test

Compressive strength of concrete is one of most important properties of concrete in most structural applications. The test was performed according to the Egyptian Code of Practice (ECP 203- 2007). Test cubes of specimens of dimensions 150 x 150 x 150 mm were cast for the used five types of concrete. Six standard cured concrete test cubes were tested at the age of 28 days, to determine the actual compressive strength of concrete. This section describes the most important results observed after testing of the specimens which were divided in two groups, seven days and 28 days, each group consisting of three tested cubes. All results showed in table (2)

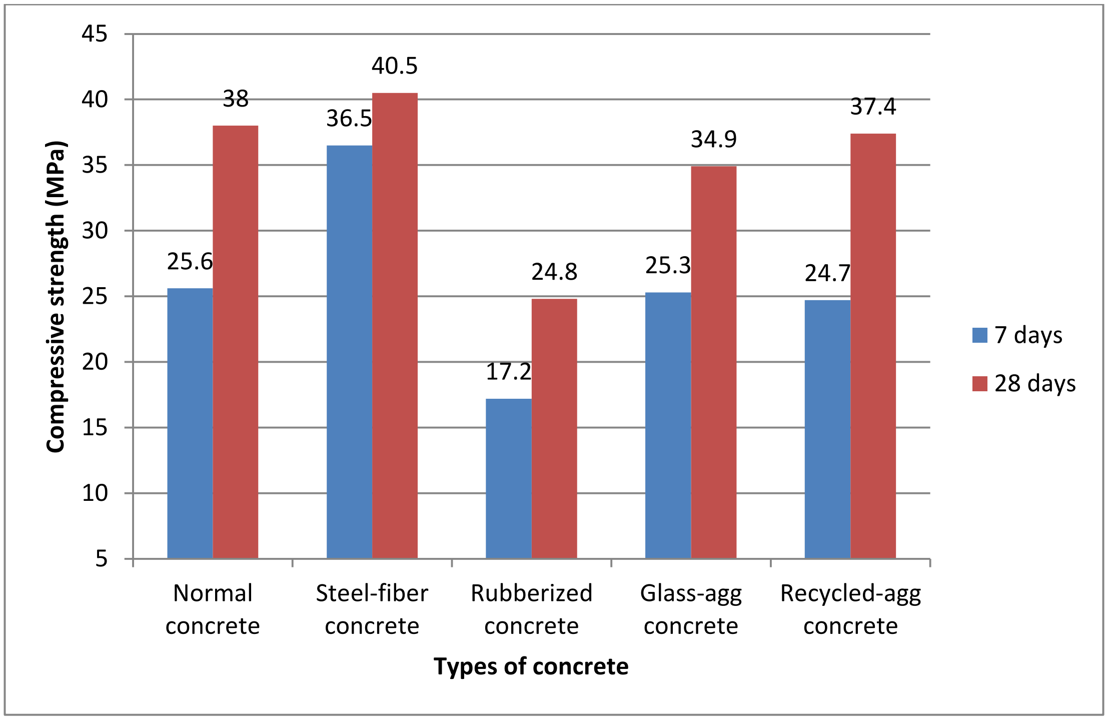

Fig (2) Result of compressive strength of (7&28days).

According to test results:

- Steel-fiber concrete mix type was the highest values (40.5MPa) of compressive strength compared to normal concrete mix (38 MPa) because of the confinement of the fiber reinforcement on the specimen similar effect is obtained by stirrups on reinforced concrete columns under vertical loads.
- Recycled aggregate concrete mix type was the second after steel-fiber and also has compressive strength values (37.4 MPa) less than normal concrete mix (38 MPa), and it was expected result as the recycled aggregate was brought from crushed concrete cubes with high compressive strength values.
- Waste glass concrete mix type was almost close values (34.9 MPa) of compressive strength with the normal concrete mix types (38 MPa) as the waste glass has similar properties to the fine aggregate (sand) but with more brittle properties than the sand.
- Rubberized concrete mix type was the lowest values (24.8 MPa) of compressive strength compared with normal concrete mix (38 MPa) and the rest types of concrete mixes as the rubber particles are much softer than the surrounding material and on loading, the cracks are initiated quickly around the rubber particles which accelerates the failure of the rubber-cement matrix, Also the soft rubber particles may behave as voids in the concrete matrix, due to the lack of adhesion between the rubber particles and the cement paste.

3.2 Pull-Out test

The pull-out test for 30 concrete cubes specimens with 150mm x150mm x 150mm was carried out for two different groups of reinforcing rebar diameters of specimens, first group with rebar diameter of 12mm and the other one is 16mm, all tests were performed after 28 days of curing. The maximum load was noted and also the mod of failure. The bond stress was calculated as following:

$$\tau_{av} = F / (\pi\, d\, L),$$

were F = maximum pull out load, d = diameter of the bar

L =embedded bar length

For each specimen pull out load and slippage and mode of failure were recorded, the bond stress at 0.1 mm slippage which acceptable as it is the allowable for category (II) structures according to ECP 203 (2018) was determined for each specimen. It presents the allowable working slippage between concrete and reinforcing bars and the results for diameter 12mm and 16mm will discussed in table (6) and table (7).

Specimen Code	Cube Num.	Force (kN)	Bond Str. (MPa)	Ave. Bond Str. (MPa)	Bond Str. at 0.1 mm (MPa)	Slipp. (mm) at Max. Load	Ave. Slipp. (mm)	mode of failure
NC-Ø12	1	46	20.34	19.7	8.1	0.256	0.249	PO
	2	45	19.9		6.9	0.288		PO
	3	43	19		9.4	0.222		PO
SFC-Ø12	1	56	24.8	24.8	9.1	0.244	0.242	PO
	2	58	25.7		10.2	0.243		PO
	3	54	23.9		9.6	0.234		PO
RC-Ø12	1	28	12.4	12.1	4.7	0.357	0.346	PO
	2	26	11.5		4.5	0.379		PO
	3	28	12.4		5.5	0.302		PO
WGC-Ø12	1	42	18.6	20.1	12.2	0.219	0.251	PO
	2	46	20.3		8.3	0.279		PO
	3	48	21.3		8.6	0.257		PO
RAC-Ø12	1	50	22.1	22.2	9.1	0.233	0.233	PO
	2	48	21.2		9.6	0.234		PO
	3	53	23.4		10.2	0.234		PO

Table: (6) Results of experimental program for bar 12mm

Where
NC: Normal Concrete.
SFC: Steel-Fiber Concrete.
RC: Rubberized concrete.
WGC: Waste Glass aggregate concrete.
RAC: Recycled Aggregate Concrete.
SP: Splitting failure.
PO: Pull out failure.

Specimen Code	Cube Num.	Force (kN)	Bond Str. (MPa)	Ave. Bond Str. (MPa)	Bond Str. at 0.1 mm (MPa)	Slipp. (mm) at Max. Load	Ave. Slipp. (mm)	mode of failure
NC-Ø16	1	51	12.7	12.3	6.4	0.292	0.266	SP
	2	48	11.9		7.3	0.233		SP
	3	50	12.4		6.6	0.273		SP
SFC-Ø16	1	63	15.7	16.8	6.1	0.260	0.261	SP
	2	72	17.9		8.5	0.262		SP
	3	68	16.9		7.2	0.261		SP
RC-Ø16	1	34	8.5	8.3	4.4	0.473	0.441	PO
	2	32	7.9		4	0.433		PO
	3	34	8.5		4.3	0.425		PO
WGC-Ø16	1	43	10.7	12.8	7.2	0.233	0.266	SP
	2	59	14.7		6.4	0.292		SP
	3	52	12.9		6.6	0.273		SP
RAC-Ø16	1	59	14.7	15	6.4	0.252	0.253	SP
	2	60	14.9		6.6	0.253		SP
	3	62	15.4		7.8	0.253		SP

Table: (7): Results of experimental program for bar 16mm.

4.DISSCUTION OF THE EXPERMENTSL RESULTS

The experimental programs were performed on five different types of concrete which is (NC, SFC, RC, WGC, and RAC). The measurements took place for different bar diameters (12, 16) with embedded length (5Ø). Therefore, a series of comparisons of the experimental test results were performed to examine the influence of changing the measurements for different bar diameters and embedded lengths that considered during performing the tests.

4.1 Effect of bar diameter on the bond strength

In general, it can be stated that the smaller the diameter of the rebar is, the higher the bond stress values will be obtained, and it was found that bond stress for cubes with rebar of diameter Ø12mm was higher than the bond stress of cubes with rebar of diameter Ø16mm by percentage varying from 32% to 39%. The main reason for this dependency the phenomenon of concrete shrinkage.

4.1.1 Bar diameter 12 mm

A) Average bond strength for cubes with 12mm rebar:

- Normal concrete got (19.7 MPa) as an average bond strength after 28 days, and it was set to be the reference for the rest results in this section.
- Steel-fiber concrete got (24.8 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete is increased by 20%.
- Rubberized concrete got (12.1 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete is decreased by 40%.
- Waste glass aggregate concrete got (20.1 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete is almost the same.
- Recycled aggregate concrete got (22.2 MPa) as an average bond strength after 28days. This means that the bond strength compared with the normal concrete is increased by 12%.

4.1.1.2 Bar diameter 16 mm

B) Average bond stress for cubes with 16mm rebar:

- Normal concrete got (12.3 MPa) as an average bond strength after 28 days, and it was set to be the reference for the rest results.
- Steel-fiber concrete got (16.8 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete with the same rebar 16 mm is increased by 37%, and compared with the same type of concrete with 12mm rebar is decreased by 32.5%.
- Rubberized concrete got (8.3 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete with the same rebar 16 mm is decreased by 33%, and compared with the same type of concrete with 12mm rebar is decreased by 32%.
- Waste glass aggregate concrete got (12.8 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete with the same rebar 16 mm is almost the same, and compared with the same type of concrete with ϕ12mm rebar is decreased by 36%.
- Recycled aggregate concrete got (15 MPa) as an average bond strength after 28 days. This means that the bond strength compared with the normal concrete with the same rebar 16 mm is increased by 22%, and compared with the same type of concrete with ϕ12mm rebar is decreased by 39%.

Table (8) and fig(3) presents the results obtained for average bond stress and the average force for the same test bar diameter 12&16 mm for all the five types of concrete mixes(NC, SFC, RC, WGC and RAC). In addition, the reduction percentage between concrete mixes values were also recorded and given in the table.

The summarizing results reveal that, the influence of changing the rebar diameter and concrete mix types causes a bond strength reduction varying from 31.4% to 37.6%.

	For Ø12		**For Ø16**		
Concrete type	**Average Force (KN)**	**Average Bond St.(MPa)**	**Average Force (KN)**	**Average Bond St.(MPa)**	**The reduction percentage %**
NC	44.7	19.7	49.7	12.3	37.6
SFC	56	24.8	67.7	16.8	32.3
RC	27.3	12.1	33.3	8.3	31.4
WGC	45.3	20.1	51.3	12.8	36.3
RAC	50.3	22.2	60.3	15	32.4

Table: (8) The Average Force and Bond Stress for bar diameter 12&16 mm.

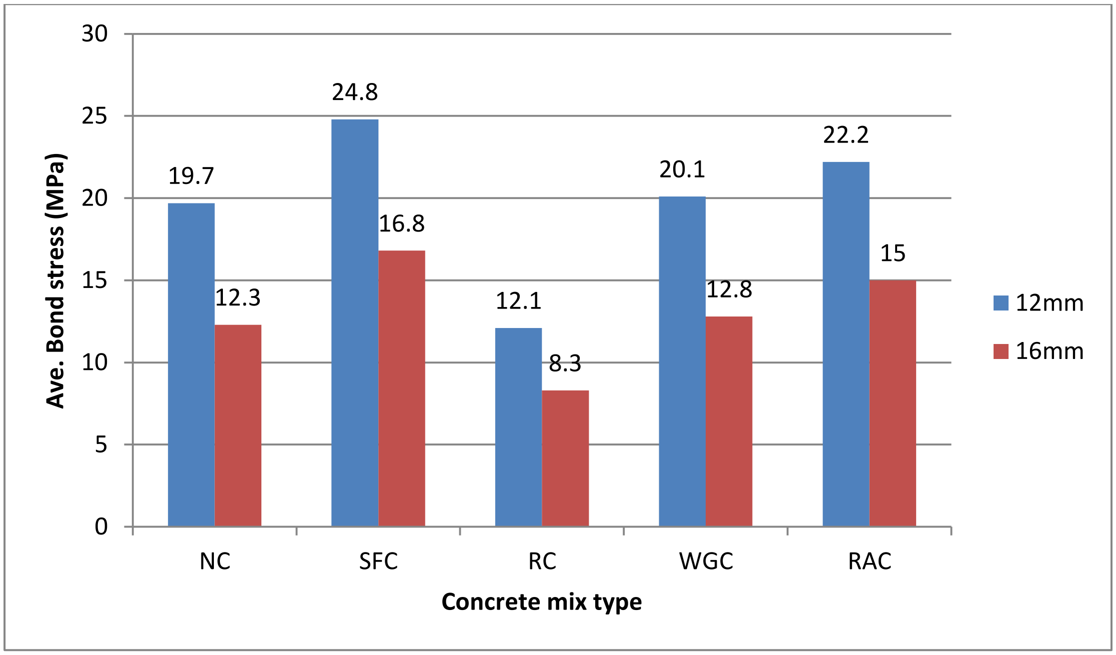

Fig: (3) The Average Bond Stress for bar diameter 12&16 mm.

4.2 Effect of concrete type

This section outlines the effect of modifications to the concrete composition on bond properties. This study on bond strength was based on different mixtures of varying compositions, which differed in the amount and type of aggregate. Either type of coarse aggregate used in concrete mixes and its appropriate composition and quality has an influence on the bond strengths. In the tests five different types of concrete mixes with different types of aggregate were made and investigated.

4.2.1 Bond strength

This part discusses how the bond strength effected by changing the type of concrete mix as following:

- Steel-fiber concrete mix type was the highest values (24.8 MPa for 12mm bar) and (16.8 MPa for 16mm bar) of bond strength compared to normal concrete mix (19.7 MPa for 12mm bar) and (12.3 MPa for 16mm bar), because of being a mechanical additive material it will not affect the chemical properties of concrete mix, the fibers create a three-dimensional support network that resists the downward pull of gravity, thus keeping aggregates in suspension and promoting uniform bleeding, also this fiber network increases the tensile strain capacity of concrete during the plastic shrinkage phase as well.
- Recycled aggregate concrete mix type was the second after steel-fiber and also has bond values (22.2 MPa for 12mm bar) and (15MPa for 16mm bar) higher than normal concrete mix (19.7 MPa for 12mm) and (12.3 MPa for 16mm bar), and it was expected result as the recycled aggregate has very rough surface because of the rest of the previous mortar which increases the bond between the other concrete composites.
- Waste glass concrete mix type was almost close values (20.1 MPa for 12mm bar) and (12.8 MPa for 16mm bar) of bond strength with the normal concrete mix types (19.7 MPa for 12mm bar) and (12.3 MPa for 16mm bar) as the waste glass has similar properties to the fine aggregate (sand).
- Rubberized concrete mix type was the lowest values (12.1 MPa for 12mm bar) and (8.3 MPa for 16mm bar) of bond strength compared with normal concrete mix (19.7 MPa for 12mm bar) and (12.3 MPa for 16mm bar) and the rest types of concrete mixes as the rubber has very weak bond properties with concrete composites.

4.2.2 Mode of failure

The effect of the concrete type on the mode of failure was discussed for the examined five types of concrete mixes (NC, SFC, RC, WGC and RAC) for the all specimens. As shown in table (9) the mode of failure for the five types of concrete mixes both pull-out or splitting failure it's dependent on the test of the specimen on the laboratory.

It was noted that all the specimens with 12 mm rebar (NC, SFC, RC, WGC, and RAC) got pull-out failure, and it was common mode of failure for all of them, however most of specimens of 16 mm rebar (NC, SFC, WGC, and RAC) got splitting failure except the RC mix got pull-out failure as it has very poor bond characteristics.

Specimen Code	The mode of failure for bar diameter 12mm	The mode of failure for bar diameter 16mm
NC	Pull-out	Splitting
SFC	Pull-out	Splitting
RC	Pull-out	Pull-out
WGC	Pull-out	Splitting
RAC	Pull-out	Splitting

Table (9): The mode of failure for the five types of concrete

4.2.2.1 Effect of bar diameter on mode of failure

It was clearly obvious that the rebar diameter has an effect on the type of mode of failure. It was observed that the smaller diameter of rebar the higher values of bond strength and getting only pull-out failure, and the higher of rebar diameter the lower of bond strength and getting splitting failure. Thus 12mm rebar specimens were the best choice for best results of bond stress.

5. CONCLUSION

The main conclusions obtained from this study can be summarized as follows:

1. The waste glass aggregate concrete (WGC) bond strength failure loads were found close to the normal concrete (NC) bond strength failure loads.
2. The bar diameter size is directly proportional to the failure loads.
3. The rubberized concrete (RC) wasn't reliable for usage as it got low values of bond strength due to the rubber has very weak bond properties due to its weak characteristics of bond between rubber and concrete.
4. Generally, slippage of rubberized concrete was higher than all of other types.
5. The bar diameter effects on slippage value.
6. Mode of failure depends on the bar diameter and concrete type.
7. Steel Fiber concrete (SFC), and recycled aggregate concrete were the most reliable concrete mixes as they have good values of bond strength.

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