Research on Engineering Structures & Materials
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Research Article

Bond behavior investigation of steel rebars embedded in basalt fiber reinforced recycled aggregate concrete

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Article Info

Article History:

Received: 17 June 2026

Accepted: 31 July 2026

Keywords:

Reinforced concrete;
Bond strength;
Recycled aggregate concrete;
Basalt fiber

Abstract

The bond strength between steel reinforcement and concrete is one of the most important physical properties that determine the performance of reinforced concrete. This research aims to study the bond behavior between reinforcing bars and recycled aggregate concrete reinforced with basalt fibers and containing recycled concrete aggregate. An experimental study was conducted on fifteen samples using a push-out test to investigate the bond strength for several variables. Seven variables were studied in this study: the natural aggregate replacement ratio, compressive strength of the concrete, basalt fibers content, thickness of concrete cover, embedded length of bar, diameter of the reinforcing steel, and the yield strength of reinforcement. The results showed a 20% decrease in bond strength at 100% aggregate replacement compared with conventional concrete. Bond strength improved with increasing compressive strength and thickness of concrete cover by 35% and 49%, respectively, when compressive strength increased from 25 to 45 MPa and concrete cover from 67 to 117 mm. Bonding behavior also improved significantly when the yield stress was increased from 420 to 650 MPa, with an improvement ratio of 32%. Regarding the bar diameter and embedded length, it was observed that increasing the diameter from 16 to 25 mm and increasing the embedded length from 7d to 12db mm resulted in a clear decrease in bonding strength, reaching 36% and 40% respectively. Adding basalt fibers in low percentage content, not exceeding 1%, does not significantly affect bond strength or failure mode. However, increasing the fiber content to 1.5% increased bond strength by approximately 15% compared to 1%.

1. Introduction

Reinforced concrete is one of the most widely used construction materials in the world throughout history due to its structural properties and high resistance to various applied loads and stresses [1-3]. One of the most important factors affecting the overall performance of reinforced concrete structures is the integration between the concrete and reinforcing steel to ensure the effective transfer of various loads and stresses [4]. With increasing urbanization, rising demand for building materials, and a growing focus on environmental considerations, developing sustainable concrete materials with suitable structural performance has become one of the most significant challenges facing the construction sector [5]. Bonding between reinforcing steel and concrete is one of the most important factors controlling the performance and efficiency of reinforced concrete elements. It ensures the transfer of forces and stresses between them and achieves their combined function and behavior. Bond strength and behavior are affected by several factors, such as the strength of the concrete, the diameter and surface texture of the reinforcing bar, the embedded, the type of aggregate used, and the characteristics of the interfacial transition zone between the concrete paste and the steel. Therefore, the bond behavior between these two materials receives considerable

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DOI: http://dx.doi.org/10.17515/resm2026-1762ma0617rs

attention in academic studies related to improving the structural performance of concrete structures [6,7]. In line with the global trend towards sustainability and reducing construction-related environmental pollution, the use of recycled aggregates derived from demolition waste has emerged as a fractional or complete substitution for traditional aggregates used in concrete. This is due to the achievement of both environmental and economic goals, such as mitigating the depletion of virgin resources and decreasing the amount of construction waste and carbon emissions. On the other hand, the use of this type of aggregate may affect some of the mechanical properties of concrete, such as its bond behavior, due to differences in the physical properties of recycled aggregates, such as their higher water absorption rate compared to traditional aggregates. Therefore, further studies are necessary to evaluate its effect on the performance of reinforced concrete [8,9]. On the other hand, basalt fibers are considered a fine-grained reinforcing material with satisfactory mechanical properties, including high tensile strength, efficient abrasion resistance, and compatibility with sustainability requirements. Numerous studies have shown that adding basalt fibers to concrete mixes can improve crack resistance, increase ductility, and positively develop the bond behavior between concrete and reinforcing steel by enhancing the homogeneity of the cement paste and delaying the development of micro-cracks [10,11,12].

Some studies have been conducted that focus on the bonding behavior between concrete and steel, such as [13], which concluded that when short embedded lengths of rebars are used (less than or equal to 5 times the bar diameter), the ultimate bond stresses are very close for different diameters of bars when the same failure pattern occurs. Likewise, [14] study concluded that increasing the rebar diameter leads to a decrease in bond strength, ranging from 10-40% depending on the surface type. Regarding the concrete cover, the study concluded that the minimum recommended amount is three times the rebar diameter to avoid splitting failure, and that increasing the cover to more than seven times the diameter does not provide a significant improvement in bond strength, also [15] concluded that rebars with diameter of 10–12 mm achieved a bond strength of approximately 15–35% higher than larger diameters (20–25 mm). Regarding basalt fiber reinforcement, according to [16] an improvement in the bond strength between concrete and reinforcing steel was observed, ranging from 5–20%. Other studies [16,17] showed that the compressive strength of concrete is the most influential factor on bond strength (30–50%), while the effect of the concrete cover-to-rebar diameter ratio may represent about 20–40% of the factors affecting the failure mode. On the other hand, the results of [18] indicated that the use of recycled aggregate may lead to a decrease in cohesion strength of approximately 10–25% when replaced at 100%, without relying on compressive strength, while [19] noted that the reduction reached 35% at the same replacement ratio. Although previous studies have been conducted on recycled aggregates and basalt fibers separately, as mentioned above, research's investigating their combined effect on the bond strength remains limited. Therefore, this research aims to evaluate and study the effect of this combination, with its various variables, on the bond behavior and sustainable reinforced concrete performance.

2. Experimental Program

2.1. Materials

In this study, concrete mixes were prepared using Portland cement grade R42.5, tested according to Iraqi Standard Specification No. 5 of 2019 [20]. Fine aggregate conforming to Zone 2 and natural coarse aggregate with a size range of 5–20 mm was used. Both types of aggregate were tested according to Iraqi Standard Specification No. 45 of 1984 [21].

Table 1. Physical characteristics of aggregate used

Physical properties	Natural fine aggregate	Natural coarse aggregate	Coarse recycled aggregate
Particle's gradation	Zone 2	5-20mm	5-20mm
Water absorption (%)	2.05	1.05	4.41
Bulk density (kg/m3)	1588	1615	1375
Specific density	2.61	2.63	2.52

Twenty-four hours after casting, the specimens were demolded and then placed in a water curing tank at a temperature of 23 ± 2 °C according to [25] for 28 days. All material tests were conducted in the laboratories of the University of Technology, Iraq. Table 1 shows the main physical properties of the aggregates used in the study. Basalt fibers with physical properties presented in Table 2 and demonstrated in Fig.1 were used.

Table 2. Physical characteristics of basalt fiber used

Testing item	Result
Filament diameter (μm)	17.7
Moisture content (%)	0.12
Tensile strength (MPa)	4000
Density (kg/m^3)	2700
Chopped length (mm)	6
Appearance quality (visual)	Normal

Fig. 1. Basalt fiber used

2.2 Mix Design Proportions, Casting, And Curing

This section presents the mix proportions for concrete mix containing natural aggregate (NAC) [22,23] with compressive strength of 25 MPa and recycled concrete aggregate (RAC) with varying replacement ratios (50% and 100%) for the target compressive strengths of 25, 35, and 45MPa [24]. It should be noted that the recycled aggregate was in fully saturated surface-dry state when used. The absolute volume method was used for NAC mixes, and the equivalent mix proportion method was used for RAC mixes. Table 3 shows the mix proportions for all concrete mixes to achieve the required compressive strength for each variable. After casting process, after24 hrs. from casting, the specimens were de-molded., then they placed in a water tank at a temperature of 23±2C° according to [25] for 28 days for testing.

Table 3. Mix design proportions

Target compressive strength f`c (MPa)	Type of aggregate used	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	w/c ratio
25	NAC	365	760	1060	0.5
25	RAC 50%	375	760	1060	0.51
25	RAC 100%	385	755	1060	0.55
35	RAC 100%	420	710	1015	0.41
45	RAC 100%	510	630	920	0.39

2.3 Specimen Details

In order to verify the behavior and performance of the bond between the rebars and the basalt fiber reinforced concrete containing concrete recycled aggregate, a reference cylindrical model with dimensions of 150*300 mm was adopted, with a deformed reinforcing bar embedded in the center of the specimen at a certain anchorage length and along its axial length to ensure proper completion of the push-out test to ensure symmetrical load transfer during the test. A steel plate was placed under the specimen containing a circular hole with a diameter equal to the diameter of the rebar in order to allow it to pass through, taking into account debonding the steel rebar from the top and bottom using PVC pipe, because the zones close to the top and bottom surfaces are disturbed and do not usually represent the actual behavior and indication of the bond between the steel and concrete. Fig. 2 below illustrates the details of the studied specimen.

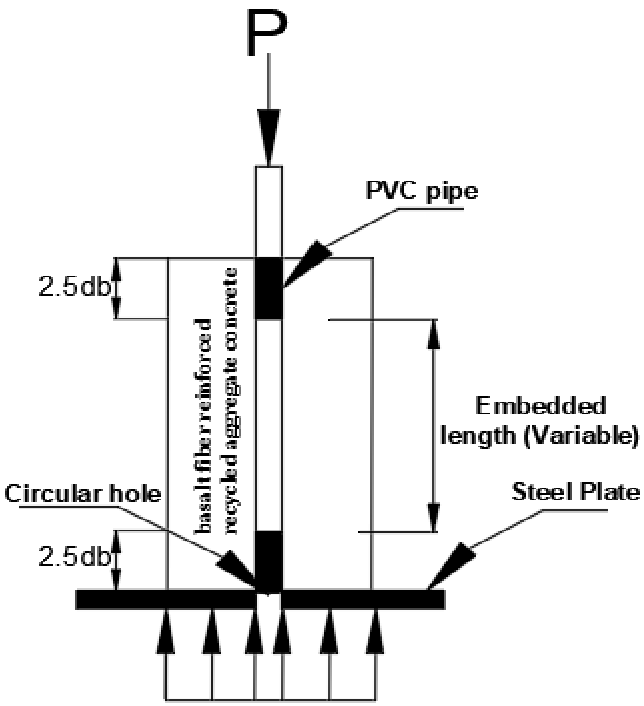


Fig. 2. Tested specimen details

2.4 Parametric study

To achieve the study's objectives and to investigate and evaluate the effect of various variables on the bonding behavior between steel and concrete containing recycled aggregates and reinforced with basalt fibers, the experimental program of the study was conducted using six main groups of models in addition to a reference model. Each group studied and focused on the effect of a single variable, while all other variables remained constant according to the values of the reference model variables. This ensured that the influence of each variable was studied individually, isolated from the others, and its contribution to the bonding behavior and performance accurately and independently determined.

The first group (Group A) investigated the influence of replacing traditional aggregate by concrete recycled aggregate at 50% and 100% replacement ratios, while the second group (Group B) focused on the effect of specimen's compressive strength (f΄c=35, 45 MPa, respectively) noting that the actual compressive strengths were 25.25, 35.42, and 45.61 MPa, respectively. The third group (Group C) evaluated the effect of the percentage of basalt fibers added to the concrete mix on bond strength. In addition, another group (Group D) assessed the effect of the concrete cover thickness surrounding the reinforcing bar, using values of 92 and 117 mm, these concrete cover values were achieved using PVC pipe molds of the required diameters. The effect of anchorage or embedded length was investigated throughout group E by studying different embedded lengths (10 db and 12 db). Meanwhile, two reinforcement diameter bars values (20 and 25mm) were studied in the sixth group (Group F) to evaluate the contribution of the bar diameter to bond strength. Finally, the last group (group G) focused on analyzing the effect of the steel yield stress. of steel. Table 4 indicates all the details related to the variables studied.

Table 4. Parametric study details

Group No.	Specimen Symbol	Agg. Replacement ratio (%)	Compressive strength f`c (MPa)	Basalt fiber content (%)	Concrete Cover (mm)	Embedded length	Rebar Size (mm)	Yield stress of rebar (MPa)
references	Bo1-Re 100%	100	25	1	67	7d	16	420
Group A	Bo2-Re50%	50	25	1	67	7d	16	420
	Bo3-Re 0%	0	25	1	67	7d	16	420
Group B	Bo4-Co 35	100	35	1	67	7d	16	420
	Bo5-Co 45	100	45	1	67	7d	16	420
Group C	Bo6-BF 0.5	100	25	0.5	67	7d	16	420
	Bo7-BF 1.5	100	25	1.5	67	7d	16	420
Group D	Bo8-CC 92	100	25	1	92	7d	16	420
	Bo9-CC 117	100	25	1	117	7d	16	420
Group E	Bo10-El 10d	100	25	1	67	10d	16	420
	Bo11-El 12d	100	25	1	67	12d	16	420
Group F	Bo12- RS 20	100	25	1	67	7d	20	420
	Bo13- RS 25	100	25	1	67	7d	25	420
Group G	Bo14-YS 350	100	25	1	67	7d	16	350
	Bo15-YS 650	100	25	1	67	7d	16	650

2.5 Test Setup and Procedure

After clarifying and presenting the details of the studied variable and models, this section will explain the mechanism and method of testing the specimens. The push-out test carried out for investigating the bonding strength behavior of all studied models. The test was performed using a universal compression testing machine with 120kN maximum capacity. The specimens were placed in the machine on a steel plate containing a hole to allow the bar to pass through during slip. The load was applied gradually to the protruding part of the bar from the top using a displacement controller with a displacement of 0.1 mm per minute. At the end of the test, the vertical slip values of the rebar corresponding to each applied load were recorded. See Fig. 3.

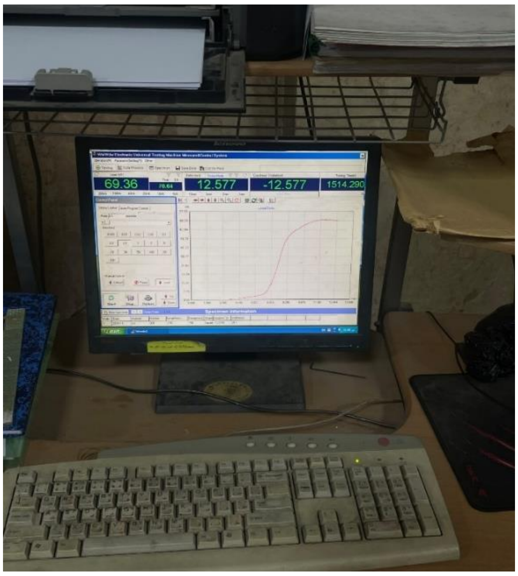


Fig. 3. Test setup

3. Results and Discussion

This section presents the results obtained from a experimental program implemented to assess the bond behavior and performance between rebars steel and concrete containing recycled aggregates and reinforced with basalt fibers. The results were analyzed separately to determine the effect of the aforementioned variables on the slip and bond strength and behavior, the various failure mechanisms associated with different specimens, and to assess the extent to which each variable contributed to improving or deteriorating bond performance. The results obtained were expressed in terms of the ultimate bond stress, which can be calculated using the equation:

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

Where; P_{ult}: the ultimate load, D: rebar diameter, ld: the embedded length of rebar into specimen.

3.1 Effect of Different Variables on Bond Strength

After testing all the studied specimens, the results were as presented in Table 5. After reviewing and analyzing the results, a deterioration in bond strength up to 20% was observed when the natural aggregate was replaced with 100% recycled concrete aggregate. This decrease is attributed to the high-water absorption capacity of of recycled aggregate due to the presence of cement mortar on its surface. Consequently, porous voids form, affecting the interfacial transition zone between reinforcement and concrete, thus reducing strength and mechanical interference rounding the rebar. When investigating the effect of concrete compressive strength f̀c on bond strength, an increase in bond strength of 18% and 34% was recorded when the compressive strength was increased to 35 and 45 MPa, respectively. This is due to the development and increase in concrete density around the rebar zone. Furthermore, the increased compressive strength delays the appearance of hairline cracks, thus providing higher bond strength before failure. The basalt fiber content also had a positive effect, as the improvement in bond strength reached 5% with an increase in the basalt content of 1% and 15% with a content of 1.5%. The addition of fibers improves bonding characteristics as a result of their role in limiting the growth and rapid spread of fine hairline cracks surrounding the bar, which enhances the cohesion of the concrete and develops the level of lateral restraint surrounding the bar, which led to increase stress transfer and thus enhance bond strength.

Table 5. Results of experimental work

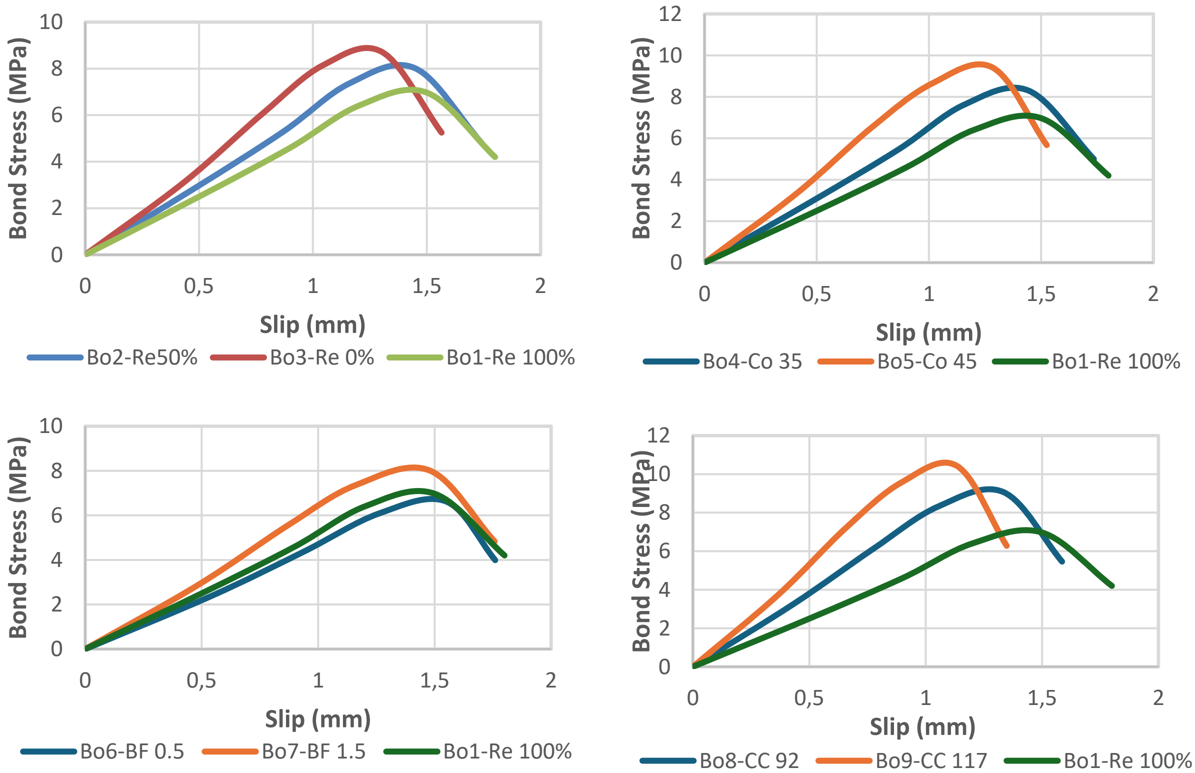
Group No.	Specimen Symbol	Ultimate Bond stress τ_{ult} (MPa)	Slip at ultimate bond stress (mm)
references Group A	Bo1-Re 100%	6.97	1.35
	Bo2-Re50%	8.05	1.31
	Bo3-Re 0%	8.71	1.26
Group B	Bo4-Co 35	8.25	1.39
	Bo5-Co 45	9.36	1.23
Group C	Bo6-BF 0.5	6.62	1.50
	Bo7-BF 1.5	8.01	1.40
Group D	Bo8-CC 92	9.06	1.28
	Bo9-CC 117	10.38	1.20
Group E	Bo10-El 10d	5.22	1.24
	Bo11-El 12d	4.25	1.49
Group F	Bo12- RS 20	5.58	1.27
	Bo13- RS 25	4.46	1.65
Group G	Bo14-YS 350	5.43	1.28
	Bo15-YS 650	9.20	1.25

Turning to the group D, it was noticed that when the section thickness of concrete cover increased from 67 to 92 mm, the bond strength increased significantly by approximately 30%. This increase was due to the improvement of confinement and lateral restriction of the rebar, and consequently, the increased mechanical interaction with the concrete. However, when the cover was increased to 117 mm (with the same percentage increase from 67mm to 92mm), the bond strength increased by a smaller percentage, which was 15% compared to the specimen of 92 mm cover. This indicates that the rate of bond strength enhancement decreases with increasing the cover. This is because the concrete confinement becomes sufficient at a certain cover to limit splitting cracks. Therefore, any additional increase in the cover does not lead to an equivalent increase in bond. Regarding the effect of embedded length and bar diameter, a decrease in bond strength was observed with increasing these parameters, this reduction is primarily attributed to the non-uniform distribution of stresses along the anchorage length; most of the stress is concentrated near the point of load application and gradually decreases with distance, meaning the length is not utilized in a linear manner.

Finally, when evaluating the role of the rebar's yield stress on bond properties, the results showed a direct relationship between yield stress and bond strength. Increasing the yield stress from 420 to 650 MPa improved the bond by 32%, as it increased the rebar's ability to transmit greater forces between the rebar and the concrete before plastic deformation began and the rebar ceased to transmit forces. Conversely, reducing the yield stress to 350 MPa where a reduction of 22% in bond strength noticed. All the aforementioned results were obtained under static loading conditions; the results are expected to change, and the bond behavior may manifest differently under dynamic loads, this could be investigated in future studies.

4. Relationship Between Bond Stress-Slip

After presenting the results and the relationship between the values of the variables, and in order to clarify the relationship between the bond stress and the corresponding slip value at an angle from the start of loading to failure, the curves shown in Figure 4 were drawn for each variable. From the figures above, it was observed that the relationship between bond stress and slip in all specimens mainly passes through three stages: In the first stage, the relationship is predominantly linear, as the bond between the two types of concrete (NAC and RAC) and the reinforcing rebar is primarily a result of chemical adhesion between the two materials at the beginning of loading. Upon turning to the second stage, and under higher load levels, the relationship begins to become nonlinear, reaching its maximum stress τ_{ult}, due to the clear contribution of mechanical interaction between the concrete and the steel.



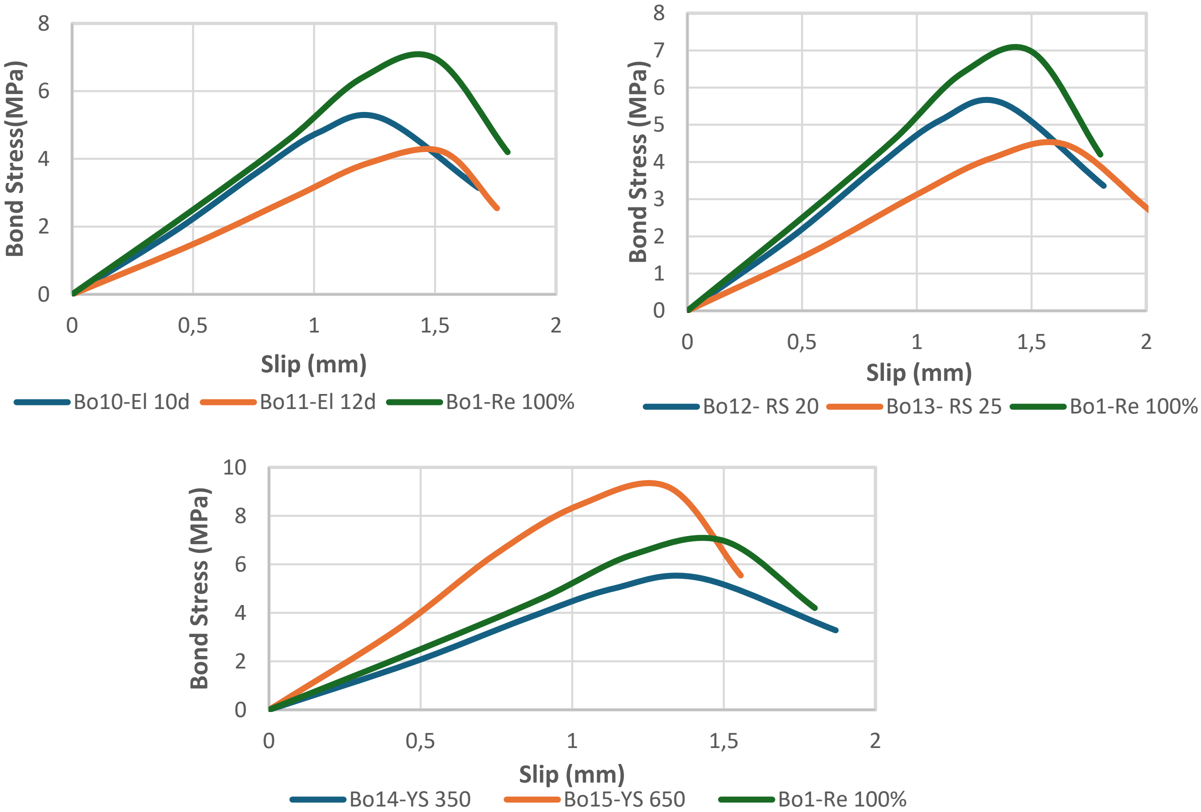


Fig. 4. Bond stress- corresponding slip relationship

At this stage, the various variables studied begin to play a more significant and pronounced role in the behavior and relationship between slip and bond stress. Finally, after the ultimate bond stress, the final stage of the curve appears: the softening stage. In this stage, the bond stress deteriorates, where its levels decrease while slippage increases significantly, leading to final failure.

5. Failure Modes of Specimens

As mentioned in the previous section, initial bonding results from friction and chemical adhesion between the bar and the cementitious material. With increasing load, the nonlinear relationship begins, and the bar slips further through the specimen. Actual bonding then develops, relying on mechanical interaction and interlocking between the steel bar and the concrete. This is accompanied by the appearance of radial tensile cracks around the bar, reaching to the softening phase and failure. For all studied specimens, two types of failure were generally observed. The first is splitting failure. This type of failure occurs when radial tensile stresses are large and dominant, resulting in longitudinal cracks on the concrete surface, eventually leading to splitting of the concrete cover. This type of failure is somewhat sudden. This type of failure was observed in higher compressive strength specimens, particularly at 45 MPa, where the increased compressive strength allows the concrete to transfer forces and stresses with steel bar, resulting in stresses sufficient to cause cracking and splitting. This type of failure was also more pronounced at higher reinforcement diameters, longer embedded lengths, and with greater yield stresses, as these provide effective stress transfer and a higher potential for crack formation. Another type of failure is "push-out" failure, which generally occurs in a more ductile manner, causing the rebar to push through the bottom of the specimen before splitting occurs. This type of failure has been observed in specimens that don't provide a high degree of mechanical interaction with the steel. The most tested specimens exhibiting this type of failure are those with a high concrete cover (92-117 mm), where the increased thickness offers better resistance to cracking and splitting, as the thick concrete prevents crack propagation. This type of failure has also been observed with increased basalt fiber content, especially at 1.5%, where the fibers bridge cracks and delay their propagation. This was also observed in specimens with a lower yield strength of 350 MPa, where less force is transferred to the concrete before yielding. Generally, splitting failure occurs when the load transfer between the concrete and steel is so sufficient that the resulting stresses exceed the concrete's capacity to resist splitting tensile cracks. Conversely, push-out failure occurs when the concrete surrounding the rebar resists these stresses until the bond between the concrete and the rebar deteriorates due to increased slippage and rebar penetration. Figure 5 and table 6 below illustrates the mode of failure for all studied specimens.

Fig. 5. Failure modes of all tested specimens

Table 6. Summary of failure modes of specimens.

Group No.	Specimen Symbol	Failure mode
references	Bo1-Re 100%	Splitting failure
Group A	Bo2-Re50%	Splitting failure
	Bo3-Re 0%	Splitting failure
Group B	Bo4-Co 35	Splitting failure
	Bo5-Co 45	Splitting failure
Group C	Bo6-BF 0.5	Splitting failure
	Bo7-BF 1.5	Push- out failure
Group D	Bo8-CC 92	Push- out failure
	Bo9-CC 117	Push- out failure
Group E	Bo10-El 10d	Splitting failure
	Bo11-El 12d	Splitting failure
Group F	Bo12- RS 20	Splitting failure
	Bo13- RS 25	Splitting failure
Group G	Bo14-YS 350	Push- out failure
	Bo15-YS 650	Splitting failure

6. Conclusions

After discussing the results related to all the specimens studied and investigate the various failure modes, these outcomes can be concluded from this work:

- The bonding strength of basalt fiber-reinforced recycled aggregate concrete decreases notably when 100% of the natural aggregate NAC is replaced with recycled concrete aggregate RAC.
- As with natural concrete aggregate, the bond stress-slip behavior of basalt fiber-reinforced recycled concrete aggregate is similar and its bond strength can be improved by increasing compressive strength, proportion of basalt fibers, thickness of the concrete cover, and also increasing the yield strength of the rebar, while it decreases with increasing the diameter and embedded length of the rebar.
- Increasing the basalt fiber content from 0.5% to 1% slightly improved the bond performance, whereas, slightly improved bonding performance was recorded, while increasing the basalt fiber content by the same percentage from 1% to 1.5% resulted in a more significant enhancement.
- Low basalt content (0.5%, 1%) did not affect the failure pattern, where splitting failure generally dominated. Conversely, when the content increased to 1.5%, the failure significantly turned to push-out failure with higher ductility.
- The mode of failure of basalt fiber-reinforced RAC is similar to that of NAC, splitting failure is common in most variables, where radial tensile stresses cause failure earlier than interlocking failure and steel slippage in concrete, except in cases where the concrete cover is thick, which can limit cracking, or where the yield stresses of the rebar are low, and high basalt fiber content in which case push-out failure is the most pronounced.
- In general, it has been demonstrated that mixtures containing recycled concrete aggregate RAC reinforcing with basalt fibers can achieve a balance between bond strength, structural performance requirements, and environmental sustainability. The fibers notably mitigated the negative effects associated with replacing conventional aggregate, thereby enabling the use of such mixtures when appropriate aggregate replacement ratios and fiber contents are employed.

Acknowledgement

The authors express gratitude the effort, assistance of all staff in college of Civil Engineering at the University of Technology for completing this work.

References

[1] Dawood M H, Rasheed S S, Al-Quraishi H, Khalil H I. Enhancing the flexural behavior of concrete beams with steel and carbon fiber. Res. Eng. Struct. Mater., 2026; 12(2): 1023-1030, http://dx.doi.org/10.17515/resm2025-1297ic1025rs

[2] Dawood MH, Izzet AF, Khudair BH. Comparative study between the behavior of the concrete thrust block and the restraint joint in a water distribution system; review. Journal of Engineering. 2022 May 1;28(5):1-0. https://doi.org/10.31026/j.eng.2022.05.01

[3] Abbas J. Mohammed, Maan S. Hassan , Hussein Al-Quraishi . Modelling the synergistic effect of waste glass and inert slag aggregate on ultrahigh-performance concrete tensile strength. Published: 08 May 2024, Volume 9, article number 192 (2024), http://doi.org/ 10.1007/s41062-024-01512-7

[4] Al-Quraishi H, Kammash K, Abdul-Husain Z. Bond strength behavior in rubberized concrete. Int J Sustain Constr Eng Technol. 2022;13(1):130-6. https://doi.org/10.30880/ijscet.2022.13.01.012

[5] Hashmi AF, Khan MS, Bilal M, Shariq M, Baqi A. Green concrete: an eco-friendly alternative to the OPC concrete. Construction. 2022 Dec 7;2(2):93-103. https://doi.org/10.15282/construction.v2i2.8710

[6] Shunmuga Vembu PR, Ammasi AK. A comprehensive review on the factors affecting bond strength in concrete. Buildings. 2023 Mar;13(3):577. https://doi.org/10.3390/buildings13030577

[7] Yalciner H, Eren O, Sensoy S. An experimental study on the bond strength between reinforcement bars and concrete as a function of concrete cover, strength and corrosion level. Cement and Concrete Research. 2012 May 1;42(5):643-55. http://dx.doi.org/10.1016/j.cemconres.2012.01.003

[8] Zhang P, Sun X, Wang F, Wang J. Mechanical properties and durability of geopolymer recycled aggregate concrete: A review. Polymers. 2023 Jan 25;15(3):615. https://doi.org/10.3390/polym15030615

[9] Marinković S, Josa I, Braymand S, Tošić N. Sustainability assessment of recycled aggregate concrete structures: A critical view on the current state-of-knowledge and practice. Structural Concrete. 2023 Apr;24(2):1956-79. https://doi.org/10.1002/suco.202201245

[10] Zhou H, Jia B, Huang H, Mou Y. Experimental study on basic mechanical properties of basalt fiber reinforced concrete. Materials. 2020 Mar 17;13(6):1362. https://doi.org/10.3390/ma13061362

[11] Jalasutram S, Sahoo DR, Matsagar V. Experimental investigation of the mechanical properties of basalt fiber-reinforced concrete. Structural Concrete. 2017 Apr;18(2):292-302. https://doi.org/10.1002/suco.201500216

[12] Vatin NI, Hematibahar M, Gebre TH. Impact of basalt fiber reinforced concrete in protected buildings: a review. Frontiers in Built Environment. 2024 May 21;10:1407327. https://doi.org/10.3389/fbuil.2024.1407327

[13] Burdziński M, Niedostatkiewicz M. Experimental-numerical analysis of the effect of bar diameter on bond in pull-out test. Buildings. 2022 Sep 5;12(9):1392. https://doi.org/10.3390/buildings12091392

[14] Başaran B, Kalkan İ, Beycioğlu A, Kasprzyk I. A review on the physical parameters affecting the bond behavior of FRP bars embedded in concrete. Polymers. 2022 Apr 28;14(9):1796. https://doi.org/10.3390/polym14091796

[15] Bažant ZP, Li Z, Thoma M. Identification of stress-slip law for bar or fiber pullout by size effect tests. Journal of engineering mechanics. 1995 May;121(5):620-5. https://doi.org/10.1061/(ASCE)0733-9399(1995)121:5(620)

[16] Fang SE, Hong HS, Zhang PH. Mechanical property tests and strength formulas of basalt fiber reinforced recycled aggregate concrete. Materials. 2018 Sep 28;11(10):1851. https://doi.org/10.3390/ma11101851

[17] Fan C, Ding Y, Zheng Y. Bond strength and failure mode prediction model for recycled aggregate concrete based on intelligent algorithm optimized support vector machine. InStructures 2025 Jan 1 (Vol. 71, p. 107999). Elsevier. https://doi.org/10.1016/j.istruc.2024.107999

[18] Basnett A, Sekar A, Nachiar S, Alaneme GU. Influence of bond strength in treated mixed recycled aggregate concrete incorporating olivine sand. Scientific Reports. 2025 Jul 1;15(1):21424. https://doi.org/10.1038/s41598-025-07551-z

[19] sahmi N, Sayhood E, Mohammed N. Bond strength of fibrous recycled aggregate reinforced concrete. Journal of Ecological Engineering. 2026;27(7):12–27. https://doi.org/10.12911/22998993/216495

[20] Central Organization for Standardization and Quality Control (COSQC). Iraqi Standard Specification No. 5/2019: Portland Cement. Baghdad (Iraq): COSQC; 2019.

[21] Central Organization for Standardization and Quality Control (COSQC). Iraqi Standard Specification No. 45/1984: Aggregate from Natural Sources for Concrete and Building Construction. Baghdad (Iraq): COSQC; 1984.

[22] R. Abdulkhudhur, M. J. Lafta, H. Al-Quraishi " Estimation the flexural-tensile strength of fiber reinforced concrete members" AIP Conf. Proc. 2864, 050005 (2024), http://doi.org/10.1063/5.0186183.

[23] Abdulkhudhur R, Dawood MH, Al-Quraishi H. Numerical Investigation for Selection the Optimal Flexural Strengthening Strategy of Reinforced Concrete Beams. Civil Engineering Journal. 2025 Oct;11(10). http://dx.doi.org/10.28991/CEJ-2025-011-10-016.

[24] Hussein Abbas Al-Quraishi, Mohammed Jaffar Hamood, Nada Sahmi, A New Shear Strength Model for UHPC Corbel, International Review of Civil Engineering, Vol 9, No 4 (2018), http://doi.org/10.15866/irece.v9i4.14868.

[25] ASTM International. ASTM C192/C192M-24: Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. West Conshohocken (PA): ASTM International; 2024.