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Impact of recycled aggregate on bond behavior between concrete and steel bars: A systematic review

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HIGHLIGHTS

- An in-depth analysis of the bond properties of steel bars in recycled coarse aggregate concrete is presented.
- The systematic review examines scientific articles from 2000 to 2023 for comprehensive data analysis.
- The relationship between recycled aggregate percentage and bond strength is now better understood.

Keywords:
Bond strength
Coarse recycled aggregate concrete
Replacement rate
Pullout tests
Corrosion of steel rebar

ABSTRACT

The use of recycled concrete aggregate (RCA) in structural applications has considerably increased in order to minimize the environmental effects of concrete buildings. Bond is a crucial characteristic of reinforced concrete that relates to the adhesion between the reinforcing steel and the surrounding concrete. This systematic review presents a comprehensive examination of the bond characteristics of steel bars and recycled coarse aggregate concrete RAC In addition, several components influencing both the load-slip curve and the failure mechanisms of RAC specimens were presented and discussed. Furthermore, prediction equations for bond strength and models of the bond-slip relationship between RAC and steel bars were summarized to enhance understanding of their applicability. The systematic review concentrated on scientific research articles to collect high-quality data, which can offer more in-depth insight into the bond behavior. The results show that several aspects influence the bond behavior of RAC specimens. These elements include the substitution rate of RCA, the steel bars' kind and size, the compressive strength, the length of embedment, and the performance of the aggregate. Both corrosion of steel rebars and cycles of freeze-thaw have an impact on the bonding performance between recycled aggregate concrete RAC and steel bars. The bonding performance between RAC and steel bars deteriorates as corrosion of steel rebars and damages from freeze-thaw approaches a particular threshold. Finally, the bonding strength of RAC exhibits an initial rise followed by a subsequent reduction with an increase in the rate of replacement of RCA.

1. Introduction

The building industry consumes considerable amounts of natural resources and energy every year, resulting in a significant amount of construction and demolition waste (CDW). The waste flow represents a considerable proportion of the overall trash generated within the European Union. Specifically, it accounts for about 30% of the total annual garbage generation, which is more than 3000 million tons [1]. The building sector has made great efforts to treat this problem through the use of recycling and the reuse of CDW in the production cycle. This approach has shown both environmental and economic feasibility [2,3], the additional benefit of mitigating the consumption of raw materials, and an obvious decrease in landfill trash volume. However, the use of CDW in the construction of flexible road pavement sub-bases is frequent, with less application as recycled aggregates (RA) for concrete production. The reason behind the limited use of RA obtained from CDW is that RA usually possesses worse quality compared to natural aggregates (NA), mostly due to their greater variability in composition. Typically, RA shows extra porosity, an elongated shape, and an increased roughness texture compared to NA [4]. When RA is utilized in concrete mixes, its natural attributes directly impact the mixtures' characteristics. Specifically, a larger amount of water is needed to provide the desired workability of the concrete due to the high porosity of the aggregates. This results in the production of recycled concrete that shows a greater level of porosity. The augmentation in the porosity of concrete results in elevated levels of water absorption [5-8] carbonation depth [7-9] and chloride-ion penetration [7,8,10] consequently diminishing its durability.

As a result, it is widely observed that recycled aggregate concrete tends to possess worse mechanical and durability-related characteristics than natural aggregate concrete. The majority of studies have reached the consensus that concrete containing

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recycled aggregates (RA) sourced from various construction and demolition waste (CDW) streams, including mixed CDW, concrete, ceramics, and glass, exhibits reduced mechanical qualities compared to natural aggregate concrete [10-13]. These mechanical values include compressive strength, tensile strength, and Young's modulus. Engineers who are interested in RCA for structural purposes to enhance the sustainability of concrete construction would be interested in understanding how the performance of RCA concrete compares to that of natural coarse aggregate concrete (NCA) under different loading conditions. Additionally, they would like to determine the extent to which the recommendations provided in existing design codes, which were primarily developed for NCA concrete, can be applied conservatively to predict the strength and behavior of structural members made with RCA concrete. A crucial factor in making sure the two materials operate together is the bonding behavior that relates to the adhesion between steel bars and concrete. This adhesion is responsible for the transmission of axial force between the two materials, guaranteeing strain compatibility and their composite action.

The bond behavior of recycled aggregate concrete RAC and steel bars is impacted by several factors, including the replacement the substitution rate of recycled concrete aggregate RCA, the steel bars' kind and size, the recycled concrete aggregate, compressive strength, and embedding length of the steel rebar [14-16]. The majority of investigations have been carried out to examine the bond behavior between RAC and steel bars using beam-end specimen tests or pull-out tests. Figure 1 exhibits the four commonest arrangements of specimens (pull-out specimen, beam-end specimen, beam specimen and splice beam specimen as show in Figure 1 a,b,c and d respectively). Etxeberria [14], considered several affecting elements to propose prediction equations of bond strength and models of bond slip for RAC and steel rebars. It has been noted that there are no longer any universally applicable equations for forecasting the bond strength and bond-slip models between RAC and steel reinforcement. Therefore, to enhance engineers' understanding of the suitability and practicality of equations predicting bond strength and models for bond-slip relationships, it was important to offer a brief overview of these existing equations and models. Furthermore, the effect of specific characteristics that were not considered in these equations and models was highlighted. the adverse conditions might accelerate the deterioration of the bond performance between RAC and steel bars, such as freeze-thaw cycles and corrosion of steel bars, as indicated by experimental work. This finding added complexity to the study [17]. Hence, to use RAC in the construction of reinforced concrete (RC), it was necessary to conduct deeper investigations on the bond behavior properties between RAC and steel reinforcement bars. This research offers a thorough assessment of the curves of bond-slip, failure modes, equations for prediction of bonding strength, models of bond-slip relationship prediction, and significant influencing variables about the bonding behavior of RAC and steel reinforcement by utilizing a systematic review that presented a wide range of high-quality data for analysis and investigated. Additionally, this study provides the bonding behavior of specimens of RAC subjected to corrosion of steel rebars and cycles of freeze-thaw.

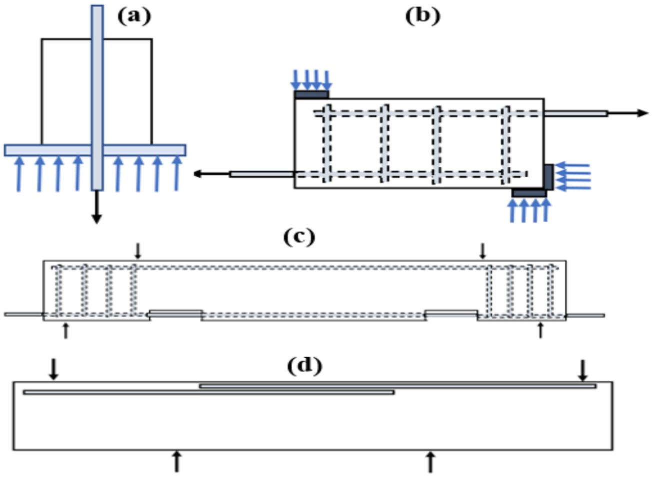


Figure 1: Display of (a) pullout specimen, (b) beam-end Specimen, (c) beam anchorage specimen, and (d) splice specimen [18]

2. Methodology

2.1 Study selection, eligibility and search strategy

The guideline Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [19] was applied for the analysis in this study. The methodology includes the use of a 27-item checklist and a flowchart [19] to facilitate the writing of a systematic review. The articles were searched using the keywords listed in Table 1. The terms that related to the alternative aggregates, such as steel slag or fly ashes, were not included in the search as the aim of this review concerned construction and demolition waste (CDW). To meet the criteria for inclusion, investigations must have been published in scientific original or review articles. This selection criterion ensures that only credible and validated findings are analyzed. Consequently, conference papers, book chapters, conference review books, and editorials were excluded. Furthermore, the chosen papers must be published in the English language between the years 2000 and 2023. This period encompasses around 78% of the overall research identified when no restrictions were imposed.

The process of identifying relevant studies was carried out using the databases of Scopus and MDPI as search engines, employing the specified keywords stated in Table 1. Following an initial screening of research titles and abstracts, every manuscript was thoroughly assessed to determine its eligibility. The data was taken from the studies that met the criteria and then processed and analyzed thoroughly.

Table 1: Keyword summary

Primary keyword	Secondary keyword	Tertiary keyword
Concrete		Bond strength
	Recycled aggregates	The pullout tests
		Compressive strength
	Recycled materials	The replacement rate of RCA
		Freeze-thaw cycles
	Recycled concrete	Steel bar corrosion

2.2 Data analysis

Various approaches for graphical depiction were used to analyze the findings of this investigation. An initial presentation was provided, outlining the quantity of data used in the research and all the reported findings. The visual representation of the data under analysis has been created using histograms, which effectively demonstrate the frequency distribution of the variables under analysis. This enables a preliminary examination of the data by evaluating the examples that show the highest level of representativeness. The second option utilized a boxplot, as seen in Figure 2. The boxplot is used to highlight the values corresponding to the first and third quartiles and the interquartile range (IQR), which included 50% of the data distribution. The median, indicated by a horizontal line inside the box, represents the second quartile. The distribution is depicted by two vertical lines, known as whiskers, that stretch to the lowest and greatest values of the data. The data points shown by the dots in this study are indicative of the outliers [20]. Finally, the third and last technique used is the scatterplot, which serves as a visual tool for representing the mechanical and physical parameters that were examined in the study. Scatterplots are used as a means of ascertaining the strength of the association between two quantitative variables. The x-axis is used to represent the independent variable, while the y-axis is used to represent the dependent variable.

2.3 Study selection

At the outset, a cumulative number of 8153 studies were discovered. Following an initial filtering process that included the exclusion of research falling under the categories of book chapters, conference reviews, and articles, only published papers and reviews were retained. As a result, a total of 5952 studies remained in the dataset. Upon implementing the second eligibility condition, which only encompasses works published between 2000 and 2023, the total count of eligible studies decreased from 5952 to 5380. After the exclusion of research published in languages other than English, the total number of qualifying studies was determined to be 4892. After eliminating duplicate entries, a total of 2690 scientific papers were retained.

Out of the total, around 1592 studies were excluded after a thorough evaluation of their titles and abstracts since they did not align with the intended focus of the research. Concerning the 1592 publications that were excluded, it can be inferred that they were either deemed inadequate in meeting the specified criteria or failed to include the designated keywords used for their retrieval. In actuality, the majority of the experiments conducted did not pertain to concrete that used recycled aggregates. Instead, they focused on alternative aggregates derived from various other recycled resources. Several studies were excluded from consideration since they primarily focused on statistical analysis rather than conducting physical testing on concrete cubes or cylinders. As a result of the final inclusion criteria, all articles about road and rail construction were excluded from the analysis. A comprehensive analysis was conducted on the whole content of the remaining 1098 articles. A total of 1048 articles failed to satisfy the inclusion criteria as previously outlined, while 50 papers met the inclusion criteria and were subjected to analysis in this study (Figure 3).

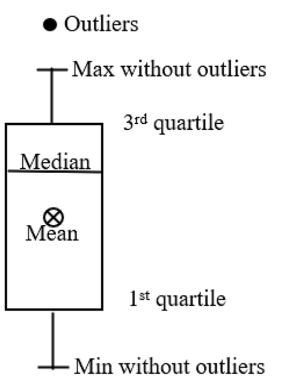


Figure 2: Box plot scheme [20]

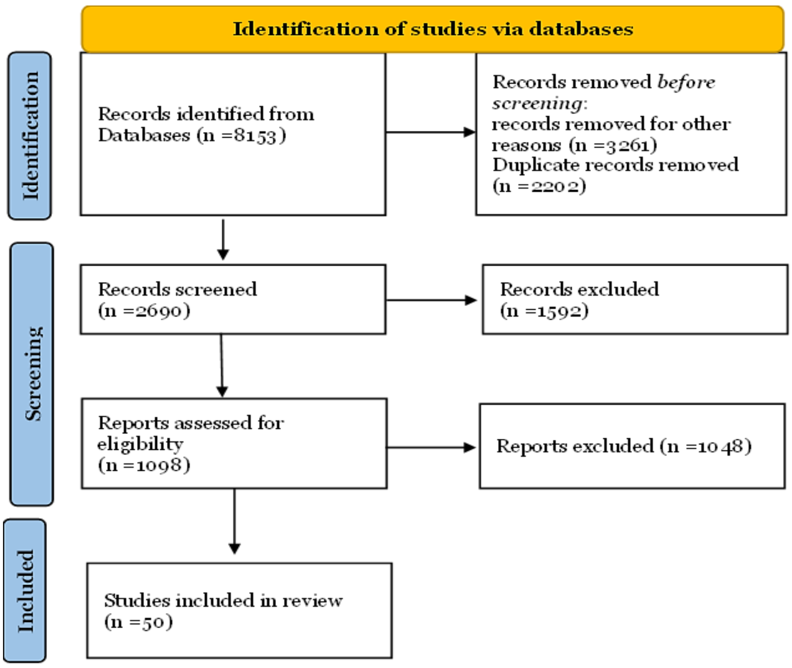


Figure 3: A flowchart using the PRISMA guidelines for extracting the eligible articles

3. Results

3.1 Modes of failure and curves of bond-slip for RAC and bar of steel

3.1.1 Modes of failure

Plate 1 displays four common failure modes observed in pull-out tests conducted on RAC specimens. Both NAC and RAC specimens exhibited identical failure modes with similar overall characteristics. However, it is noteworthy that the NAC specimens' cracks were much greater than the RAC specimens' cracks. This discrepancy can be attributed to the fact that the NAC specimens had a higher fracture energy than the RAC specimens.

(a) Pullout splitting (P-S) failure	(b) Splitting bond failure	(c) Bar fracture (BF failure)	(d) Pullout failure
During the removal of the steel bar from the RAC, visible splitting cracks were seen on the specimen surface (plate 1a) .	The RAC specimens had a brittle failure, resulting in their sudden division into two or three separate pieces (plate 1b).	The steel bar exhibited yield behavior throughout the test (plate 1c).	It was a shear failure, as shown by the occurrence of a Comparative slip between the steel bar and the (RAC). Then, the steel rebar was removed slowly from the RAC. No visible cracks are seen on the surface of the RAC specimen (plate 1 d).

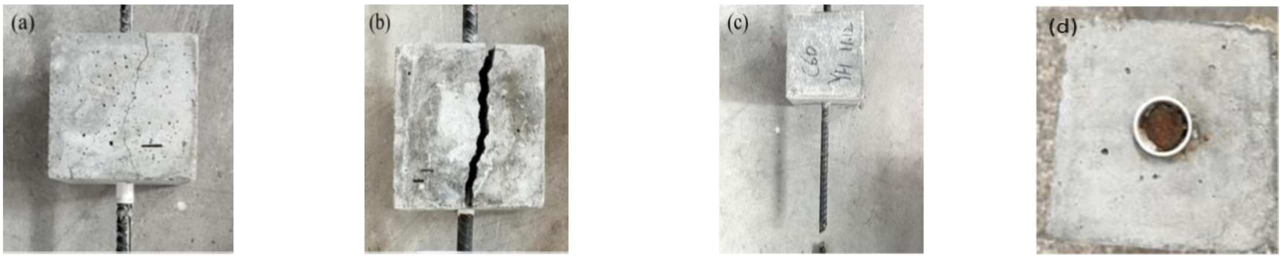


plate 1: Modes of failure

Many researchers have investigated the impact of various parameters on the failure mechanisms of recycled aggregate concrete (RAC) reinforcement with steel rebars. Various factors influenced the mechanisms of failure of the RAC specimens. These factors included the replacement rate of recycled concrete aggregates (RCA), the water-to-cement ratio (w/c), the compressive strength of the concrete, the presence of stirrups, the steel bar (type, diameter, and embedding length), and the depth of the concrete cover, as shown in Table 2, which offers a summarized overview of the findings from the literature sources referenced [17, 21- 27]. As a result, it's important to take into account how different factors may affect how RAC specimens fail. Moreover, specific factors are interconnected and can be treated as influencing factors, like the water-cement ratio (w/c) or the RCA percentage rate in connection to concrete strength, depth of concrete cover, and diameter of steel bars (c/d).

Table 2: Important variable affecting the mode of failure

Important variable on the mode of failure	Influence on the mode of failure	Ref.
w/c	The mode failure converted from pullout failure to P-S failure and to splitting failure as the water-to-cement ratio decreased from 0.51 to 0.46 and 0.33.	[17]
RCA percentage rate (r%)	The failure mode of w/c 0.46 was modified from S-P to pullout failure, with an increase in the r% from 60% to 100%.	
Steel bar diameter	The specimens of RCA using a smaller steel rebar diameter (Ø = 12 mm) exhibited a greater number of radial cracks and narrower crack widths compared to those with larger diameters.	[21]
Cover depth	Regardless of the length of embedded or compressive strength of the concrete, a P-S bond failure occurred, and cracks appeared on the surface of the RCA specimen when the concrete cover depth was very low.	[22]
Embedment length	The failure mechanism seen in RAC specimens with a lower embedment length (5d) was pullout failure, whereas specimens with a greater embedment length (10d) had BF failure. This was consistent and independent of the steel rebar diameter, depth of concrete cover, and strength of the concrete.	[23]
Steel bar type	While samples with plain steel rebars showed pullout bond failure, RAC samples with deformed steel rebars showed either splitting failure or P-S bond failure as the failure mechanism	[24]
Stirrups	The presence of a stirrup might impact the failure mechanism of the RAC samples and minimize the disparity in bond behavior between the NAC and RAC specimens.	[25]
Cover depth and Concrete strength	The failure mechanism seen in RAC specimens with a significant covering depth and relatively low compressive strength was identified as a pull-out failure. Conversely, splitting failure occurs when the depth of the covering is insufficient, and the compressive strength is quite high.	[26]
Replacement rate of RCA (%), steel bar diameter, concrete strength, and the yield stress of reinforcing bar	When all these conditions are heightened, it leads to a splitting failure characterized by an increase in fracture width on the surface of the concrete. However, when the concrete cover was increased, it resulted in a pull-out failure accompanied by a little concrete fracture on the surface.	[27]

3.1.2 Bond-slip curves

Prior studies have shown that there is no significant difference in the bond behavior features between the NAC (normal aggregate concrete) and RAC (recycled aggregate concrete) pull-out specimens. The ascending and descending branches, as well as the curves of load-slip of RAC samples, were found to be essentially identical to those of NAC specimens. This finding was corroborated by other studies [17], [28-31] as well as Xiao and Falkner [24]. Additionally, they discovered that, in contrast to NAC specimens, the RAC specimens' ascending portion of the curve of load-slip displayed a more noticeable nonlinear tendency. The result matched the conclusions reported by Kim and Yun [32].

Generally, the following stages of bond behavior are typically seen in the curves of load-slip of RAC samples with pullout bond failure or P-S bond failure:

Phase I was distinguished by the absence of any observable slip rate, and adhesion was the primary factor contributing to bond resistance.

1) **Micro-Slip Stage:** The relationship between load and slip is linear, with a little load and no noticeable slide at the free end of the rebar.
2) **The Internal Cracking Stage:** During the internal cracking stage, the load reaches a critical point, and the free end of the rebar begins to slide, indicating a near collapse of the adhesion force.

In Phase II the slip rate rose noticeably, and the climbing section of the curve displayed clear nonlinearity. Mechanical interlock was the primary factor contributing to bond resistance, with a minor contribution from frictional resistance caused by wedging action.

1) **Pullout Stage:** A few longitudinal splitting cracks spread along the weakest section of the concrete cover when the load approaches the maximum load (Pmax).
2) **Descending Stage:** The steel bar is fully drawn out as the load drops quickly and the slip increases.
3) **Residual Stage:** The displacement of the loading end reaches a certain level; the load stabilizes and is about less than half of the maximum load.

The steps mentioned are implicit in the load-slip relationships shown in Figure 4. The curves of bond-slip of RAC samples experiencing splitting bond failure or bar fracture (BF) failure were found to be incomplete, consisting only of the ascending section. Numerous studies have been carried out to examine the impact of different parameters on the load-slip curves of RAC, including steel bars. Pour and Alam [33], observed that when the ratio of concrete cover to diameter increases, the pullout section becomes less apparent. Additionally, due to the increasing toughness, the slope of the descending section is very insignificant. Prince [31,34,35] observed that as the diameter of the steel bar increased, the ascending section of the load-slip curves of RAC exhibited almost linear behavior until reaching the maximum load. The presence of internal cracking and pullout phenomena was not clearly evident.

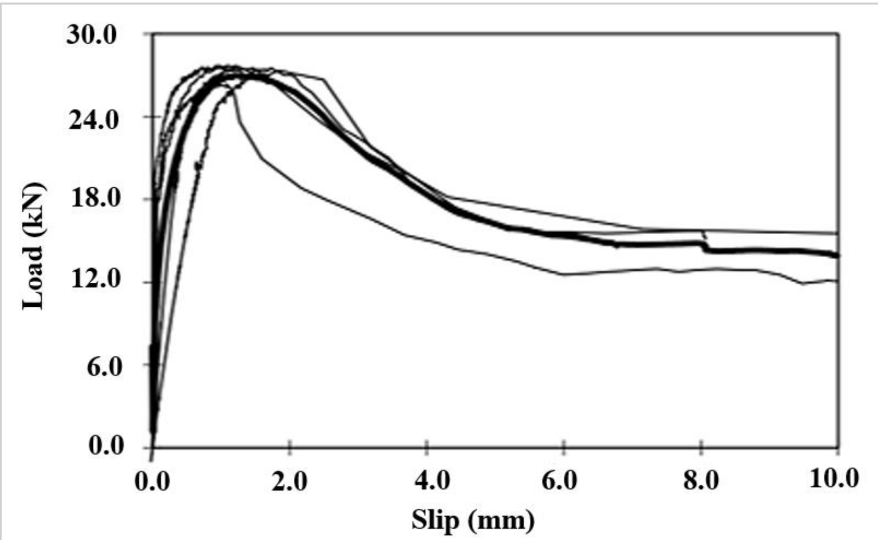


Figure 4: Curves of load versus slip [24]

3.2 Equations for predicting bonding strength and models for describing the bond-slip connection

3.2.1 Equations for predicting bonding strength

Various Equations for predicting bonding strength between RAC and steel bars have been developed based on experimental data. These Equations, along with their corresponding factors, are compiled and presented in Table 3. The purpose is to compare these equations and gain a deeper understanding of the factors that influence bond strength. It is evident that important aspects, such as confinement by transverse reinforcement and fiber reinforcement, are not incorporated in the bond strength prediction models, so additional research is needed.

Figure 4 compares the experimental values of [23], which were specimens made with varying ratios of fine and coarse recycled aggregates Figure 5a, with the predicted data obtained using the equations in Table 4. In addition, experimental values of [21], which were specimens made with varying ratios of coarse recycled aggregates only Figure 5b, are also shown. The prediction equation developed by Kim and Yum [32] is very appropriate for RAC specimens that include both recycled coarse aggregate (RCA) and recycled fine aggregate (RFA). However, it tends to overstate the value of specimens that do not contain RFA, such as those in [21]. The disparity between the actual value and the predicted value, as calculated by the equation proposed by Reiterman et al. [17], was minimal. Furthermore, this equation is very suitable for recycled aggregates, both fine and coarse, as well as for coarse aggregates alone. The cause is that the estimated formula proposed by Reiterman et al. [17] depends on the average density of the coarse aggregates, which has a respectable effect on the bond strength when using pull-out specimens. This effect is more noticeable than the impact of the structural characteristics, such as c/d and ld/d, which are more apparent in beam specimens. This is shown by the predictive equation developed by Wardeh et al. [23], which underestimated the bond strength due to an exaggerated consideration of c/d, ld/d, and the replacement rate of RCA.

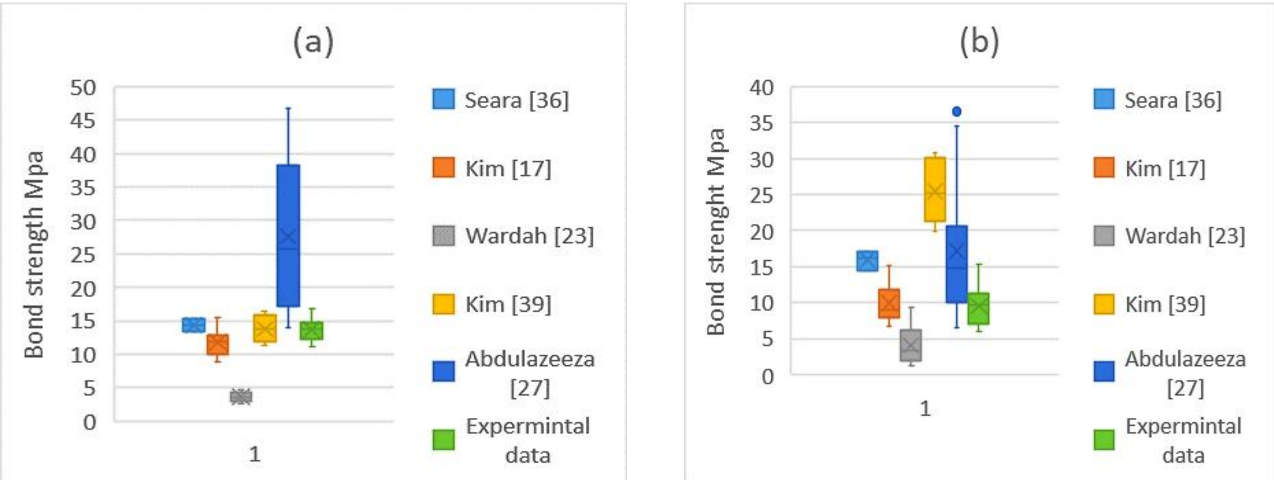


Figure 5: Comparison of equations and experimental bond strength values: (a) with fine and coarse recycled aggregates. (b) with coarse recycled aggregates only

Table 3: Predictive equations of bond strength

Predictive equations	Considered influencing factor	Ignored influencing factor	Ref.
$\tau_{max}=2.\sqrt{f_{cm}}(1-0.124\gamma/100)$	▪ f'c ▪ RACr%	▪ ρ_{AVE} ▪ d_b ▪ c ▪ RFAr% ▪ l_d	[36]
$r=1.039\times[0.925\frac{\rho_{AVE}}{\rho_{NCA}}]^{[\frac{4}{(0.04F_c)^3}]}$ $r=\frac{\tau_{RCA}}{\tau_{NCA}}$ $F_c=\begin{cases}30 & f'_c\le 30\\ f'_c & other\ cases\end{cases}$	▪ ρ_{AVE} ▪ f'c	▪ d_b ▪ c ▪ RF/ ▪ l_d ▪ RACr%	[17]
$\tau_{max}=\frac{\left[-0.33+0.4\left(\frac{c}{d}\right)+9.5\left(\frac{d}{l_d}\right)\right]}{1+0.125\gamma}\sqrt{f_{cm}}$	▪ f'c ▪ d_b ▪ c ▪ l_d ▪ RACr%	▪ RFAr% ▪ ρ_{AVE}	[23]
$\tau_{max}=0.614\sqrt{f_{ckr}}(c/d-0.55)-(0.4203e^{0.0172s}+0.007\gamma)$	▪ f'c ▪ d_b ▪ c ▪ RFAr% ▪ RACr	▪ l_d ▪ ρ_{AVE}	[32]
$\tau_{max}=2530(f_c)^{0.57}*\left(\frac{c^{0.03}}{d_b l_b}\right)$	▪ f'c ▪ d_b ▪ c ▪ l_d	▪ RFAr% ▪ RACr% ▪ ρ_{AVE}	[27]

Where ρAVE is the coarse aggregates average bulk density; ρNCA is the NCA density; fc is the concrete strength; τRAC and τNAC are the bond strength of RAC and NAC specimens, respectively; γ is the RCA replacement rate of recycled coarse aggregates in specimens; ld is the length of embedded; d is the diameter of steel bar; fcm is the compressive strength of cylinder; fckr is the compressive strength average cylinder value; c is the cover depth of concrete covering; S is the RFA recycled fine aggregates percentage rate in specimens.

3.2.2 Models for describing the bond-slip connection

Several researchers have used the Equations put forward by Haraji [28] Xiao and Falkner [24], Xiao et al. [37], to develop a normalized bond-slip relationship model for recycled aggregate concrete (RAC) with a steel bar. These models, together with their corresponding parameters, are summarized and shown in Table 4. As seen in Table 5, a lesser amount of parameter produced (a) a higher rising branch of the graph depending on the bond-slip relationship model, whereas a lesser amount of parameter (b) produced a finer declining branch of the graph. Previous studies have taken into account many aspects, including the compressive strength of the concrete, the diameter of the steel bars, and the rate of replacement of RCA. The values of parameters a and b will be similarly impacted by the same variables that affect the bonding-slip curve. Despite the widespread usage of the model of the bonding-slip relationship proposed by Xiao and Falkner [24] and Xiao et al. [37], there is currently no consistent regulation for determining the values of parameters (a) and (b). Furthermore, the influence of specific characteristics, like the thickness of the concrete covering, the steel rebar type, the embedding length, and the existence of stirrups, on parameters (a) and (b) has not been investigated. Hence, more inquiry is required.

Table 4: Normalized bond-slip relationship model and influence factors

Normalized bond-slip relationship model	Parameter	The effect of different factors on parameters a and b	Ref.
$\tau' = \begin{cases} (\acute{S})^a & \acute{S} \le 1 \\ \dfrac{\acute{S}}{b(\acute{S}-1)^2+\acute{S}} & \acute{S} > 1 \end{cases}$ $\tau' = \dfrac{\tau}{\tau_{max}}$ $\acute{S} = \dfrac{S}{S_{max}}$	a b	- When the diameter of the steel rebar rose, Wardeh et al. found that the value of the parameter (b) decreased [23]. - Regardless of the RCA % or mix proportions, Xiao and Falkner suggest that the coefficient (a) keeps constant at 0.3. They also discovered that, in comparison to RACs with plain steel rebar, those with deformed steel rebar had values of parameter (b) that were much higher [24] -Prince and Singh [31] found that $\begin{cases} a = 0.18, b = 0.2 & \phi = 8mm \\ a = 0.2, b = 0.15 & \phi = 10mm \end{cases}$ For high-strength RAC with steel rebar.	[24, 36]
		- According to Prince and Singh [35], parameter a remained within a limited range independent of the RAC replacement rate. (Concur with Kim et al. [29]) Furthermore, there was no apparent correlation between the RCA replacement rate and the values of coefficient (b). This is applicable to many steel bar diameters. - Prince et al. [38] noted that RAC specimens' parameter (*b*) values exhibited an upward trend when the RAC replacement rate increased. But, with an 8 mm steel rebar diameter, this tendency was not noticeable.	[35][29] [38]
$twowo\tau' = \begin{cases} (\acute{S})^a & \acute{S} \le 1 \\ \left(\dfrac{1}{S}\right) + 0.15S_{max} & \acute{S} \ge 1 \end{cases}$	a	$a = 0.2$ for normal − strength (36 mpa) high − strength (68 mpa) $a = 0.3$ $for\ midium - strength\ (51\ mpa)$	[35]
$\begin{cases} \tau_{max}\left(\dfrac{s}{S_{max}}\right)^a & 0 \le s \le s_{max} \\ \tau_{max} - \left(\dfrac{\tau_{max}-\tau_c}{s_1 - s_{max}}\right)(s - s_{max}) & s_{max} \le s \le s_1 \\ \tau_c & s \le s_1 \end{cases}$	a	- Parameter (*a*) can be determined based on the experimental results.	Three A stage Model [38]

Where τ_{max}, s_{max} are the maximum strength of bond and associated slip respectively; the constants (*a*) and (*b*) were established using the results of the experiment; τ_c is the residual strength of bonding; s_1 is the residual bonding strength-corresponding slip.

3.3 Important variables that impact the behavior of bonds

3.3.1 RCA Replacement rate

Numerous studies have been undertaken to investigate the impact of the rate of replacement of RCA on the bonding behavior between RAC and steel bars. However, different perspectives persist in the available research. All the data pertains to the bond strengths derived from the pullout testing. Equation 1 was used to convert the pullout load (Pu) into the bond stress (τ) in Mpa, commonly known as the bond strength, based on the embedment length (ld) and the reinforcing bar diameter (db).

$$\tau = \frac{Pu}{\pi d_b l_d} \quad (1)$$

Figure 6 illustrates the decline in bond strength of concrete using recycled concrete aggregates (RCA) compared to concrete mixes consisting only of natural aggregates. The data set has 115 values. Approximately 71% of the data indicates a decline in the bond strength of concrete when using recycled concrete aggregate (RCA). Out of the specimens that saw a decline in bond strength, 31% had a decrease of less than 10%.

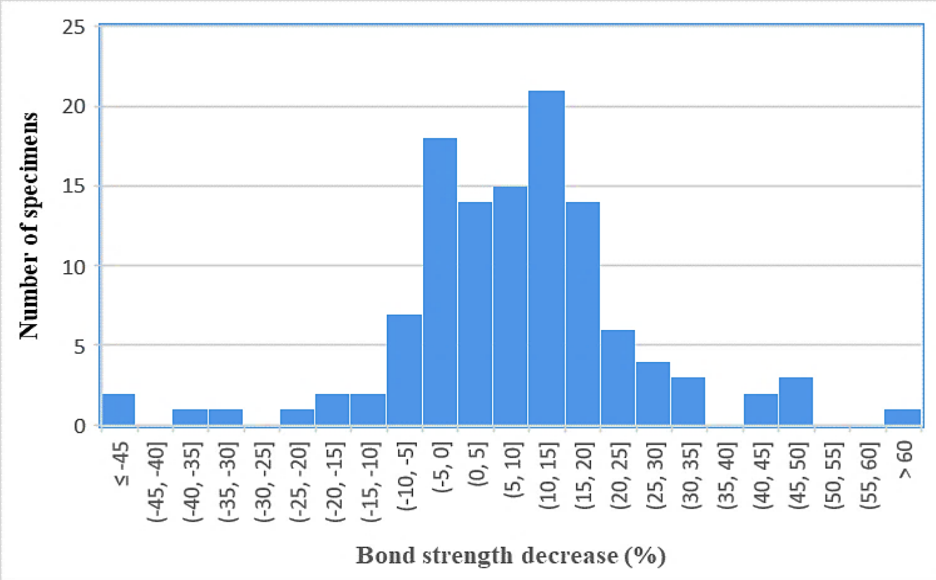
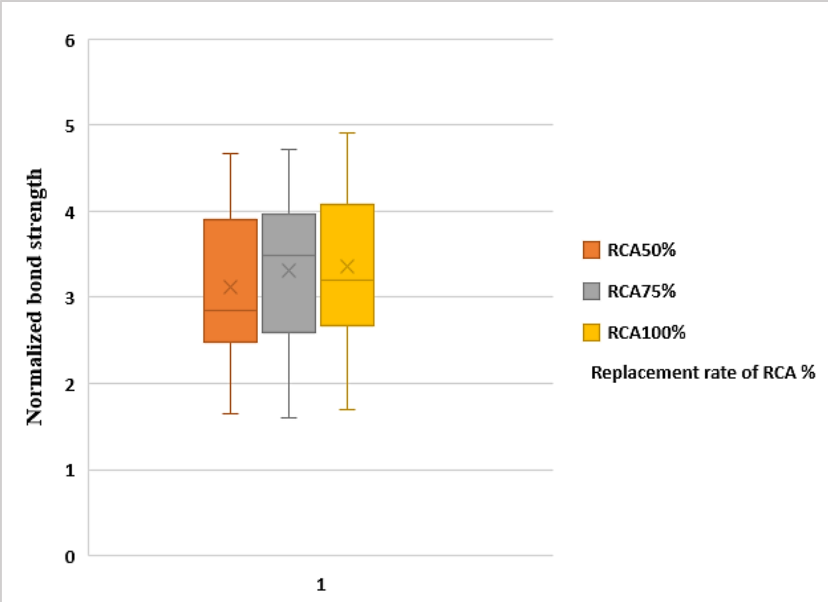


Figure 6: Amount of data of bond strength decrease for concrete containing. RCA [16,21][24- 27], [31,32], [34-36] [40-42]

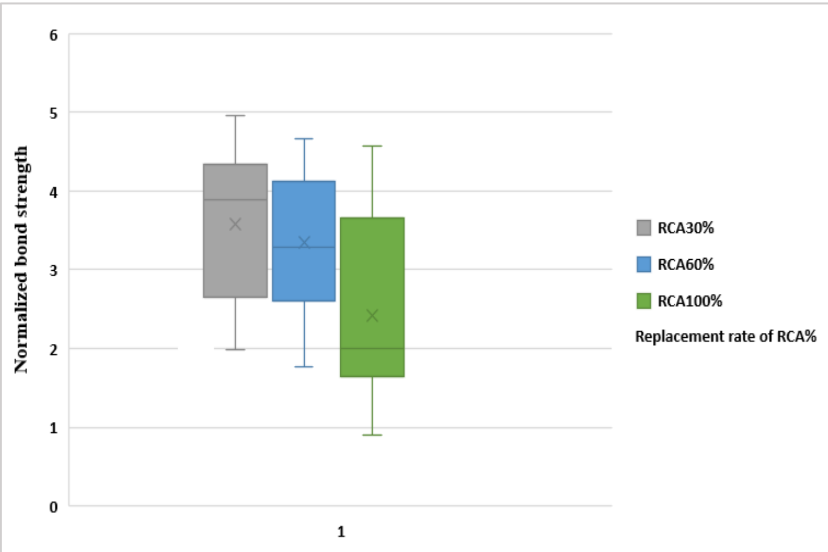
While there were differing viewpoints on the impact of the RCA on bond strength, the majority of research indicated that mechanical strength directly affects bond strength. Hence, it was essential to consider the impact of the compressive strength of RAC [36]. Several scholars have used a bonding ratio in their articles to mitigate the impact of concrete compressive strength. The square root of compressive strength is often regarded as the most suitable criterion for normalizing bond strength [23], [42,43]. In their study, Prince and Singh [35], found that the conventional method of normalizing bonding strength ($fc'^{1/2}$) oveemphasized the impact of concrete strength. However, when the measured bond strengths were normalized to ($fc'^{3/4}$), a closer correlation was observed with the test data. This normalization method also provided accurate results across all levels of RCA replacement in both normal and high-strength concrete. In cases where specimens were intended to exhibit a splitting failure mode [45] or had a varied concrete cover [46,47], the bond strength was normalized using the (fc') value.

It is important to note that in cases of pull-out failure, many researchers and coders view the ($fc'^{1/2}$) as the most suitable parameter for normalizing the bond strength. Therefore, this parameter has been used to normalize the experimental data on bond strength .A discrepancy was found in the previous study. Several prior studies have shown a positive correlation between the replacement rate of RCA and bond strength. However, contrasting findings from other studies have shown a negative relationship between the replacement rate of RCA and bond strength. In Figure 7a, the normalized bond strength is shown to increase as the replacement rate of RCA (recycled concrete aggregate) increases. This is supported by findings from various literature sources [24, 27, 31], [34,35]. These sources explain that the modulus of elasticity of recycled coarse aggregate RCA is similar to the modulus of elasticity of the cement paste, which in turn improves the mechanical properties of the interfacial transition zone (ITZ) between RCA and the cement paste. Additionally, the internal curing action of the RCA particles and the rough surface of RCA contribute to a stronger bond with the new cement paste. Similarly, Figure 7b illustrates the decline in normalized bond strength as the replacement rate of RCA increases, as indicated by various sources in the literature [16, 20, 32, 36, 42]. This can be attributed to the higher water absorption and lower density of RCA compared to NCA. Existing research has shown ongoing debates on the impact of the rate of replacement of RCA on bonding strength behavior.

The majority of researchers employed direct replacement mixtures to achieve concrete with varying rates of recycled concrete aggregate (RCA) replacement. For direct comparison, Figure 8 illustrates the normalized bond strength for different replacement ratios of RCA. The results were obtained from various sources [17, 21, 24, 27],[31,32][34-36],[42], which included the data used in Figures 7 (a and b) beside other data collected in order to create Figure 8. It is evident that the bonding strength of RAC exhibits an initial rise followed by a subsequent reduction with an increase in the rate of replacement of RCA. Nevertheless, it constantly maintains a greater level compared to natural aggregate concrete (NAC). The RCA continues to absorb the free water as it is being cured, diminishing the impact of the water-cement (w/c) ratio. When the RCA replacement rate is high, the reduction of the influence of the water-cement(w/c) ratio becomes a secondary factor in increasing strength. In contrast, the loss in strength is mostly determined by many undesirable conditions, such as increased discreteness, a high mud content, and a greater crushing index, which becomes the crucial factor [47]. This conclusion is similar to the findings of Hu et al. [48] but more realistic due to the wide range of high-quality data. Among the data, 10% RCA exhibited a comparable normalized bond strength with NCA due to the low value of RCA%. While the percentage of RCA reaches 50%, it indicates the limit when the impact of these two factors becomes equal, and the dominance of one of them depends on the conditions of the mixture. In these mixtures, the concrete's composition is altered solely by substituting natural coarse aggregate (NCA) with RCA while keeping other properties, such as water-cement proportions, consistent. However, the impact of various levels of RCA replacement on the compressive strength of concrete was not considered. Butler et al. [22], examined the bonding strength between RAC and steel bars using two different concrete mixture proportions.



(a)



(b)

Figure 7: The correlation between normalized bond strength and RCA replacement rates a) positive correlation. b) inverse correlation

The first group, RCA-1, included replacement mixes that preserved the initial water-cement proportions. On the other hand, the group of RCA-2 was specifically designed to achieve equivalent compressive strengths in concrete. The experimental results demonstrated that the bond strengths of beam-end concrete specimens made with natural aggregate were higher than 19% and 21.3% of those made with RCA-1 and RCA-2, respectively. These results indicate that replacing natural aggregate with RCA may have a strong effect on the bond strength of steel bars, even when the concrete strengths are the same. So, it was important to examine the effect of replacement rates of recycled concrete aggregate (RCA) on concrete compressive strength and assess its influence on bond strength when analyzing. The proportional change of the concrete mix is a good method to lower the impact of the compressive strength of concrete on bonding strength rather than using normalized bond strength for this purpose. Finally, in order to address the quality issues of RAC, much research has been conducted to enhance its characteristics by modifying particle gradation, reinforcing the concrete interface, and using admixtures. Recent studies have consistently demonstrated that steel fibers, when used as a reinforcing material, may effectively prevent the creation and spread of cracks in concrete. In addition, it has been demonstrated that the steel fiber reinforced recycled aggregate concrete (SFRAC) specimens often exhibit a ductile failure in comparison to RAC specimens with the same combination proportions [49– 52]. The mechanical characteristics exhibit a positive correlation with the volumetric ratio of steel fibers. The bond strength exhibits a similar trend. Additionally, the bond failure mechanism of SFRAC specimens was ductile. This was because the cracks in SFRAC did not rapidly enlarge upon reaching the point of creaking strength. The observed trend may be attributed to the proper utilization of SF, which successfully stops the development and expansion of both micro and macro cracks. As a result, the steel rebar experiences a higher degree of confinement [53]. This approach shows significant promise for broader application in future research.

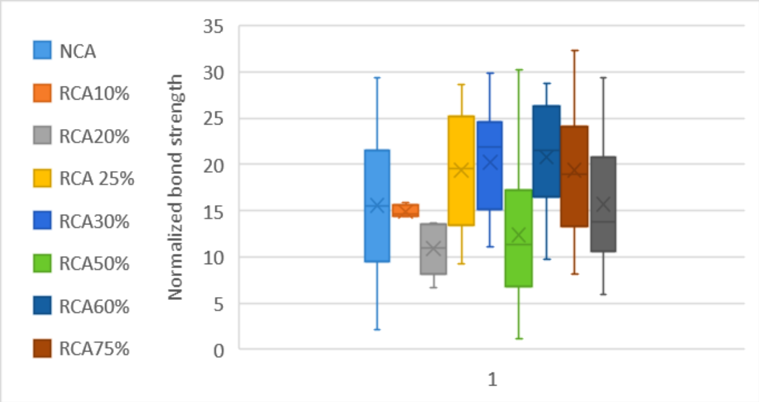


Figure 8: Normalized bond strength for various replacement rates of recycled concrete aggregate (r%)

3.3.2 Concrete compressive strength

The bonding behavior of RAC with steel bars was significantly influenced by the compressive strength of the concrete. In their study, Breccolotti and Materazzi [41], examined the bond strength between reinforcing steel and recycled aggregate concrete (RAC). The findings indicated a reduction in both the bond strength and compressive strength of RAC as the rate of recycled aggregates increased. Seara-Paz et al. [36], Prince and Singh [31], Prince and Singh [39], Esfahani and Rangan [54], and Kim et al. [26], as well as Prince and Singh [34] reached a similar result that the normalized bond strength exhibited a consistent tendency to increase alongside compressive strength. The prevailing hypothesis is that the brittleness index is positively correlated with both the compressive strength of concrete and the bond strength. Nevertheless, a limited number of tests indicate that there was a slight decrease in the final bond strength when the compressive strength of the concrete rose. Generally, the bond strength, which was determined in these articles, had a positive correlation with the concrete's compressive strength. Figure 9 illustrates that the bond strength, when normalized, has a positive correlation with the magnitude of the compressive force. The robustness of RCA was evaluated based on the findings extracted from the literature sources [17, 21, 36, 42].

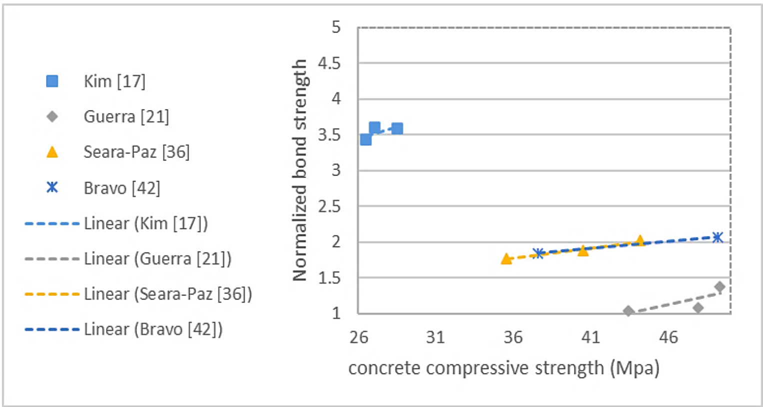


Figure 9: Normalized bond strength versus concrete compressive strength

3.3.3 Aggregate properties

Kim et al. [26] and Sun-Woo et al. [29], found a significant relationship between the bond strength of RAC specimens and the average density and average water absorption of the RCA. The bond strength had a negative correlation with the average water absorption, but it demonstrated a positive correlation with the average density. Nevertheless, the impact of the recycled coarse aggregate on the bond strength was shown to be statistically insignificant in cases where the compressive strength of the concrete was high. The average absorption of water and bulk density of RCA was evaluated using Equations 2 and 3, respectively.

$$\text{WAave} = \frac{\Sigma \text{ each coarse aggregate weight} * \text{relevant water absorption }\%}{\text{Total weight of coarse aggregate}} \quad (2)$$

$$\rho\text{ave} = \frac{\Sigma\text{each coarse aggregate weight} * \text{ relevant density}}{\text{Total weight of coarse aggregate}} \quad (3)$$

Kim and Yun [32], noticed that the bonding strength of RAC was impacted by the size of the recycled concrete aggregate (RCA). Particularly, when comparing pullout specimens at the 28-day age with the same RCA replacement ratio, it was observed that RAC specimens including smaller aggregate sizes show higher bond strength compared to those including larger aggregate sizes. The results show that the bonding strength of the RCA is impacted by the size of the aggregate, which is the result of the mostly spherical form of recycled aggregate concrete (RAC). Then, due to the circular shape of the RACs, the phenomenon of segregation is concentrated along the process of flow. According to the results of Butler et al. [22], there is a direct inverse relationship between the bond strength of RAC and the crushing value of RCA, indicating that RCA with a lower crushing value demonstrates greater splice strength and fracture energy [55,56]. Moreover, Assaad et al. [40], reported a significant reduction in the ultimate bond strength (τu) when using RCA obtained from low-strength and lightweight parent concrete (PC). This means that the quality of the PC directly affects the transmission of stresses and bonds to the embedded steel bars. This phenomenon may be due to the decreased strength of the bond between the steel ribs and the old mortar, leading to a possible decrease in the interfacial shear stresses. Conversely, ultimate bond strength (τu) shows an increase when concrete includes RCA from high strength (PC).

3.3.4 Steel bar embedment length

Several researchers have undertaken studies investigating the impact of the length of steel bar embedment on the bond strength between recycled aggregate concrete (RAC) and steel bars [21, 23, 27, 32, 38]. The study conducted by Pour and Alam [33], revealed a negative correlation between bond strength and the length of steel bar embedment. The bond strength of reinforced recycled aggregate concrete (RAC) with an embedment length of 10 times the diameter of the steel bar (denoted as "d") was found to be around 50% to 70% of the bond strength observed with an embedment length of 5 times the diameter of the steel bar. The findings of Wardeh et al. [23], Cao et al. [38], and Abdulazeeza et al. [27], were consistent. The causes are as follows: The number of ribs on the steel bar rises proportionally with the length of embedding. On the other aspect, the force that holds the RAC and the steel bar together is spread across a longer length, causing a reduction in the strength of the bond between them. In a study conducted by Guerra et al. [21], it was found that the length of the steel rebar's anchoring does not affect the stress distribution in the steel-concrete contact.

3.3.5 Bar properties (steel rebar type and diameter)

The type and the diameter of the steel bar are two additional significant variables that impact the bond strength of RAC with steel rebar, in addition to the concrete compressive strength and the RCA replacement rate.

3.3.5.1 Bar diameter

Cao et al. [38], and Prince et al. [34,35], observed that the normalized bond strength of RAC was comparatively lower when larger steel bar diameters were used, as opposed to smaller steel bar diameters. This observation aligns with the results reported by Pour and Alam [33], who also observed a drop in bond strength between recycled aggregate concrete (RAC) and steel bars as the diameter of the steel bars increased. The causes are as follows: Increasing the diameter of the steel bar leads to an increase in the contact interface between the RAC and the steel bar, but a reduction in the bond stress imparted to the RAC. Additionally, the number of ribs reduces with the increase in steel bar diameter for the same embedment length. The normalized bond strength values obtained from the literature sources [27], [33-35] were computed and graphed in Figure 10. The graph illustrates a decreasing trend in normalized bond strength as the diameter of the steel bar increases.

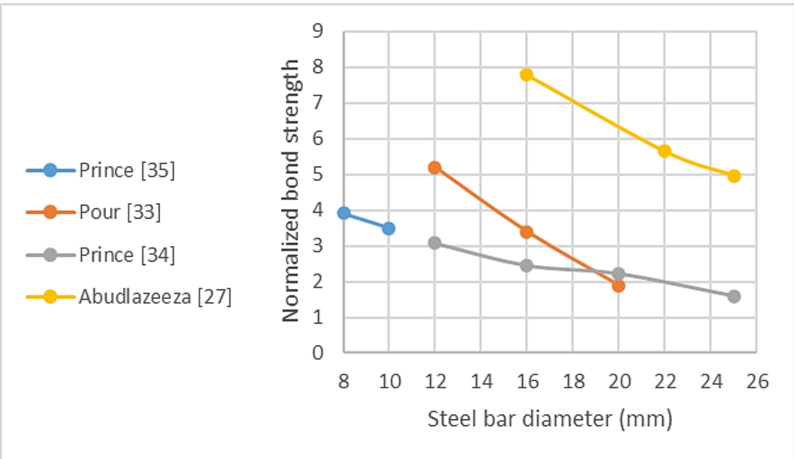


Figure 10: Bonding strength normalized against steel rebar diameter

3.3.5.2 Bar type

The impact of steel rebar type on the behavior of bonding between RAC and steel rebar was examined by Xiao and Falkner [24], and Cao et al., [38]. They discovered that the bonding strength between RAC and bar with ribs (deformed rebar) exceeded that without ribs (plain bar). The correlation between the steel rebar type and the bond strength of RAC specimens is shown in Figure 11. This figure illustrates how much stronger the RAC bond was with deformed steel bars compared with plain steel bars.

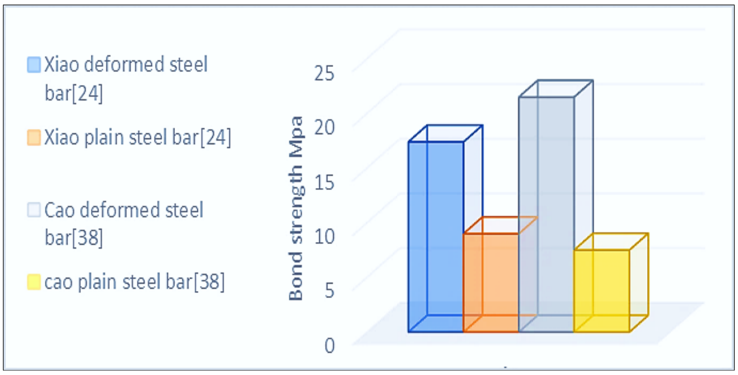


Figure 11: Bond strength versus steel bar type

According to Xiao and Falkner [24], the explanation for this outcome is that the deformed rebars may offer more excellent friction resistance and mechanical anchoring. In contrast, the bond between RCA and plain bars is primarily determined by the adhesion between concrete and steel, which is significantly affected by the proportion of replacement of RCA. This finding elucidates that the bond strength between the recycled aggregate concrete and the deformed rebar is remarkably similar (concerning plain bars), regardless of the proportion of RCA replacement. Consequently, one important aspect influencing the strength of the bond between RAC and steel rebar was the type of steel rebar. The RAC members should choose the deformed steel bar to provide optimal bonding performance between the steel bar and the RAC. The primary factor influencing the bond strength between RAC and a deformed steel bar is the mechanical interlocking force generated by the interaction between the ribs on the steel bar and the RAC. The key geometric characteristics of the steel rebars that impact these mechanical interlocking forces are the height of the ribs and the distance between ribs. In the case of a steel bar with a consistent diameter, it can be seen that there is an increase in rib height and a decrease in the distance between ribs. This lead enhances the mechanical biting effect. The height and distance of ribs of steel in rebars are subject to variation based on the diameter of the bars. When comparing the bonding strength of RAC with varying rebar of steel diameters, it is essential to analyze the properties of the bars as influential elements.

3.3.6 Others parameters

Numerous researchers have conducted investigations on various characteristics that impact the bond strength of RAC with steel bars. These studies, together with their corresponding parameters, have been compiled and presented in Table 5.

Table 5: Various characteristics impact the bound strength of RAC with steel bars

Relating parameters	Results of study	Ref.
Concrete cover depth	The bond strength exhibited a positive correlation with the depth of the concrete cover. The bond strength of RAC specimens with a concrete cover of 67.5 mm exhibited a 50% increase compared to those with a concrete cover of 42.5 mm. The rationale for this observation is that the specimens with a greater concrete cover exhibit a higher degree of confinement.	[33]
Curing time	The bond strength of RAC exhibited a notable rise between the 7-day and 28-day curing periods. However, there was no improvement in bond strength seen between the 28-day and 365-day durations.	[36]
Bar locations	The study observed that the presence of bleeding, segregation, and surface settling exhibited a greater magnitude in the RCA specimen as compared to the NCA specimen, particularly in the top reinforcement bars.	[32]
The arrangement direction of reinforcing bar	-The study found that there was no significant disparity in bond strength and slip between high-strength concrete and deformed reinforcing bar when considering vertical and top-bottom horizontal reinforcing bar, together with the replacement rate of recycled material.	[26]
Stirrups	The bond strength in beam specimens reinforced with stirrups demonstrated higher values, indicating that the lateral reinforcement offers adequate confinement. As a result, this leads to an enhancement of the frictional forces between the steel bars and the concrete, preserving the bond strength at a higher level, and successfully diminishing the disparity between the behaviors of the NAC and RAC beams. [36]. The crack widths seen in the confined specimens were roughly half the magnitude of those observed in the unconfined specimens, owing to the presence of stirrups that provided confinement. The crack widths seen in the confined specimens of both NAC and RAC were found to be quite similar. Consequently, for the laterally constrained specimens, the impact of the material properties of the various concrete types, namely NAC and RAC, on crack width appears to be minimal.	[25]
Concrete age	The bond strength exhibited a positive correlation with the progress of concrete age.	[57]
	There were no notable differences seen in the progression of bonding strength over time between the NAC and RAC.	[32]

3.4 Influence of steel bar corrosion and freeze-thaw cycles on bond behavior

3.4.1 The corrosion of steel rebar

Numerous investigations of the bond properties of RAC and rusted steel reinforcing bars have been carried out. According to Lei [58] and Zhao et al. [25], it has been shown that the bond strength of recycled aggregate concrete (RAC) specimens exhibits an initial rise followed by a subsequent drop with an increase in the level of corrosion of steel bars. Huaishuas et al. [59], also provided evidence that the deterioration of bond strength in RAC specimens due to corrosion was comparable to that in natural aggregate concrete (NAC) specimens [59,60]. However, the deterioration of bonding strength in recycled aggregate concrete (RAC) with corroded steel rebar was significantly more pronounced compared to that in natural aggregate concrete (NAC) with corroded steel rebar. According to Zhao et al. [25], the bond strength of the RAC specimens with stirrups remained very stable despite the varying degrees of steel bar degradation. In a study conducted by Fernandez et al. [61], it was observed that the bond strength of RAC specimens with uncorroded steel bars exhibited similar performance to that of NAC specimens. However, RAC samples showing minimal steel bar corrosion rates indicated better bond strength compared to NAC specimens. All of the aforementioned research expedited the corrosion process of steel bars through the use of electrochemical means, resulting in a reduction in the overall duration of the experiments. However, its ability to accurately simulate corrosion mode is limited, thereby limiting its ability to accurately represent the real effect of corrosion [62].

3.4.2 Freeze-thaw cycles

The performance of concrete is influenced by the freeze-thaw cycle, which subsequently impacts the bond behavior between concrete and steel bars [18]. Several investigations have been conducted to examine the bonding performance RAC and steel bars during freeze-thaw cycles. Shang et al. [63], used a pull-out test to explore the bond behavior of RAC, which undergoes cycles of freeze-thaw. The results demonstrated that when the number of cycles of freeze-thaw increased, strength of bonding decreased, and the slip associated with maximum strength of bonding increased. This agrees with the conclusions obtained by Su et al., [64], Wang et al. [65], and Shang et al. [63], the cause is the degradation of RAC's mechanical characteristics and its internal structure loosens after freeze-thaw cycles [66,67]. Shang et al. [59] showed that the impact of cycles of freezing and thawing on the bonding strength of RAC samples in the absence of air-entraining admixture was significantly greater than that of the usage of air-entraining admixture. Li et al. [60], studied the influence of various replacement rates of RCA after freeze-thaw cycles on the bond behavior of RAC specimens. When the number of cycles of freezing and freezing was limited, the researchers noted that the bonding strength of RAC samples was comparatively less than that of natural aggregate concrete (NAC) samples. However, the strength of bonding of RAC samples exceeded that of NAC samples as the number of freeze-thaw cycles increased. Su et al. [68,69] examined the bonding behavior of RAC and steel bars following cycles of salt and frost.

The results indicate that the bond strength of RAC samples submerged in a salt solution exhibits a faster decline and more slip compared to those submerged in water. Generally, After the extent of damage caused by freeze-thaw and steel bar corrosion reaches a critical threshold, the bonding behavior between RAC and steel bars is adversely affected. Hence, it exposes the structural integrity of RAC to risk. For structural safety, it was necessary to conduct a deep examination of the bonding characteristics of RAC and steel reinforcement bars, as well as identify strategies to mitigate any possibility of degradation in bond behavior. Moreover, the advancement of nanomaterial technology, such as graphene [70,71], has been seen by researchers to have a positive impact on enhancing the properties and Concrete's performance. In subsequent searches, graphene has the potential to increase the durability of reinforced RAC specimens. Additional research is required to examine the bonding behavior of beam specimens to better simulate the structural elements in structures.

4. Future perspective

The majority of investigations have been carried out to examine the bond behavior between recycled aggregate concrete (RAC) and steel bars, using pull-out tests or beam-end specimen tests, while the large-scale beams made of recycled aggregate concrete are not examined. Hence, it is evident that there is a clear requirement for more research on the bond behavior of tension bars for large-scale structural recycled aggregate concrete (RAC) beams. Future research must encompass the influence of various factors on the bond stress-slip relationship, as well as the bond stress-compressive strain relationship in recycled aggregate reinforced concrete beams. These parameters encompass modifications in the components of recycled aggregate concrete, particularly variations in the proportion of recycled aggregate and the quantity of steel fibers incorporated. The investigation must concentrate on changes in beam design, including the size of the primary tension bar, development length, addition of stirrups, and thickness of concrete cover at the tension face. After extensive research, new formulae must be developed especially for recycled aggregate concrete beams in order to determine the bond strength and development length between the surrounding concrete and steel reinforcing bars. In addition, these new prediction formulae need to consider environmental exposure and long-term durability after deeply investigation of various environmental conditions. Moreover, it is required to construct more beam specimens and attach strain gauges to the steel bars along the section between the free end and the notch end in order to examine and investigate the distribution of bond stress in the beam specimens. It is widely acknowledged that structural members constructed from steel fiber recycled coarse aggregate concrete SFRCA have similar qualities to those of standard concrete members [72-75]. Consequently, the combination of RAC and fibers is technically feasible and offers significant environmental advantages in engineering applications, Thus, more study is necessary to assess and develop new formulations for the bonding behavior of SFRCA in beam specimens and use fibers manufactured from waste steel, so offering an additional means of mitigating waste concerns.

5. Conclusion

This study thoroughly examines the bond behavior between recycled aggregate concrete (RAC) and a steel bar. To evaluate the utilization of recycled aggregate in the construction industry to mitigate the environmental impacts of concrete structures, it is essential to understand the performance of recycled aggregate concrete under various conditions, in contrast to natural aggregate concrete (NCA) especially the bond behavior which represented a crucial characteristic of reinforced concrete. Depending on the analysis, the following conclusions may be drawn:

1) The prediction Equations of bond and models of bond-slip relationship for bond strength between RAC and steel reinforcement have been collected for further study, analysis, and understanding of their practicality and suitability. For predictive equations, the analysis shows that all of these equations consider the main factor, namely the compressive strength of the concrete. None of these equations take into account the presence of stirrups. On the other hand, for bond-slip relationship models, there is a lack of a standardized method for the selection of parameters (a), (b), and the effect of a number of variables, like the thickness of the concrete covering, length of embedment, and presence of stirrups. Therefore, additional research is essential to addressing this knowledge gap.
2) The bond behavior of RAC specimens, including the failure modes, is impacted by many main factors, including the replacement rate of RCA, the compressive strength of the concrete, the type and diameter of the steel bars, the embedment length of the steel bars, and the performance of the aggregate. The bonding strength of recycled aggregate concrete (RAC) demonstrates an initial increase, which is subsequently followed by a decline when the rate of replacement of recycled concrete aggregate (RCA) increases. Moreover, the failure modes shown by specimens of RAC and those in NAC specimens were similar
3) It's essential to take into account how different influencing interconnected factors may affect how RAC specimens fail, like the water-cement ratio (w/c) or the RCA percentage rate to concrete strength, depth of concrete cover, and diameter of steel bars (c/d).
4) To examine the influence of recycled aggregate concrete ratio on bond strength, independent of the impact of compressive strength. Modifying the proportions of the concrete mix efficiently mitigates the impact of compressive strength on bond strength, rather than opting for normalized bond strength for this purpose.
5) Both freeze-thaw cycles and steel rebar corrosion have an impact on the bonding behavior between RAC and steel bars. The bonding behavior of RAC with steel bars deteriorates when the extent of damage caused by freeze-thaw and steel bar corrosion have a defined threshold, further compromising the structural integrity of the RAC.

Nomenclature

a and b	Constants obtain from experimental work
BF	Bar fracture failure
c	Depth of cover, mm
CDW	Construction and Demolition Waste
d_b	Steel bar diameter, mm
fc'	Concrete strength, Mpa
f_{ckr}	Mean value of cylinder compressive strength, Mpa
f_{cm}	Cylinder compressive strength, mpa
ITZ	The interfacial transition zone between RCA and the cement paste
l_d	The embedded length, mm
NA	Natural aggregate
NCA	Natural coarse aggregate concrete
Pmax	The maximum load, KN
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
P-S	Pullout splitting failure
Pu	The pullout load, KN
r%	RCA replacement rate
S_1	The slippage associated to the residual bond strength, mm
S_{max}	Slippage associated to the ultimate bond strength, mm
S	Replacement rate of RFA

Greek symbols

τ	Bond stress, Mpa
τ_c	Residual bond strength, Mpa
τ_{max}	Ultimate bond strength, Mpa
τ_{NAC}	Bond strength of NAC specimens, Mpa
γ	Replacement rate of RCA
ρ_{AVE}	Average density of the coarse aggregates, Kg/m^3
ρ_{NCA}	Density of the NCA, Kg/m^3

Author contributions

Conceptualization, **N. Sahmi**, **E. Sayhood** and **N. Mohammed**; data curation, **N. Sahmi**; formal analysis, **E. Sayhood**, **N. Mohammed**, **N. Sahmi**; investigation, **N. Sahmi**; methodology, **E. Sayhood** and **N. Mohammed**; project administration, **E. Sayhood** and **N. Mohammed**; resources, **N. Sahmi**; software, **N.Sahmi**; supervision, **E. Sayhood** and **N. Mohammed**; validation, **E. Sayhood**, **N. Mohammed** and **N. Sahmi**; visualization, **N. Sahmi**; writing—original draft preparation, **N. Sahmi**; writing—review and editing, **E. Sayhood** and **N. Mohammed**. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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