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(Research Article)

Bonding of new structural members into existing structure using locally available epoxy resins

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Abstract

The utilization of various epoxy resin adhesives for bonding new structural elements into existing structures serves to enhance the overall functionality and longevity of the infrastructure. Understanding and employing these practices effectively enable cost-effective retrofitting techniques, facilitating the safe and efficient improvement of existing structures.

The methodology adopted for conducting pullout tests adhered to The Standard Test Method for Bond Strength of Epoxy Resin Systems Used with Concrete, following ASTM (882-78, 1983). A total of 81 concrete cube samples were utilized, comprising various grades ranging from C20 to C30, and reinforcing bars of diameters 10mm, 12mm, and 16mm, with corresponding embedded lengths of 60mm, 70mm, and 90mm. The testing apparatus, including the jig attachment, was constructed and employed as per established protocols.

The bond stress using AB 4minutes adhesive at 9.3mm rebar: 6.67, 6.78 and 10.16N/mm^2. At 11.40m rebar: 4.92, 4.96 and 7.92N/mm^2. At 15.2mm rebar: 4.81,4.90 and 5.98N/mm^2. The bond stress using Araldite adhesive at 9.3mm rebar: 8.01, 9.12 and 12.6N/mm^2. At 11.40m rebar: 6.81, 7.69 and 10.07N/mm^2. At 15.2mm rebar: 5.90, 6.31 and 7.16N/mm^2. The bond stress using Hilti-Re100 adhesive at 9.3mm rebar: 22.54, 27.17 and 28.04N/mm^2. At 11.40m rebar: 13.03, 17.74 and 18.71N/mm^2. At 15.2mm rebar: 5.78, 8.28 and 8.69N/mm^2. Analysis of the results revealed a progressive increase in the bond strength from the AB 4- minute adhesive to Araldite and Hilti-Re100. There are significant improvements in bond strength were observed with increasing concrete grades, underscoring the importance of selecting appropriate concrete grade for optimal bonding outcomes and also it was observed that the bond stress decreases as the bar diameter increases.

The economic viability of using Araldite and AB 4-minute adhesives for retrofitting applications was evident, signifying their practical utility in structural enhancement projects. The desirable properties exhibited by epoxy resin adhesives, including thermal stability, adhesive strength, toughness, and electrical conductivity, contribute to achieving superior bonding performance compared to traditional cement paste methods. The insights gained from this research provide valuable guidance for selecting suitable adhesive to enhance bonding between existing and new structural elements thereby improving the strength, functionality, and aesthetics of buildings and infrastructure to extend their service life and ensuring their long-term sustainability.

Keywords: Epoxy Resins Adhesives; Retrofitting; AB 4 minutes; Araldite and Hilti- Re100

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1. Introduction

The imperative to effectively bond concrete and reinforcing bars in structural design, especially for various construction projects, emphasizes the criticality of understanding the bonding dynamics of new structural members to existing structures through the use of epoxy resin adhesives. This focus is supported by the pioneering work of Achillides and Pilakoutas (2004), who conducted an in-depth study on the bond behavior of fiber-reinforced polymer bars under direct pullout conditions. Their findings underscore the effectiveness of epoxy resin adhesives in the post-installation enhancement of structural elements, including staircases, columns, beams, and extensions, thereby augmenting the structural integrity and performance.

This research explores the integration of new structural members into existing frameworks using a spectrum of epoxy resin adhesives, guided by the Building Code Requirement for Structural Concrete (ACI 318-02) and its accompanying commentary ACI 318R-02, as set forth by the American Concrete Institute. (Hamad et al. 2006) provide a detailed analysis focusing on the bond strength facilitated by both bonded-in and post-installed reinforcement methods. The absence of a robust bond can lead to issues like cracking and spalling, undermining the structure's durability and leading to potential failure. (Cairns and Abdullah 1996) underscored the negative implications of inadequate bonding, such as increased friction and shear stress at the rebar-concrete interface, which are crucial factors affecting a structure's serviceability and resilience.

The research conducted by (Charles et al. 2018) and (Otunyo and Kennedy 2018) underscores the detrimental impact of corrosion on the bond between steel reinforcement and concrete, advocating for the use of epoxy resins as a preventative measure against corrosive damage and structural failure. Such insights are critical for the development of durable and reliable reinforced concrete structures, ensuring their serviceability and safety over extended periods.

This study aims to identify the locally available epoxy resin type suitable for integrating structural members such as beams, columns, slabs, and stairs into existing structures. components such as beams, columns, slabs, and stairs within pre-existing frameworks. Utilizing the Standard Test Method for Bond Strength of Epoxy Resin Systems Used with Concrete, according to (ASTM 882-78, 1983) standards, this analysis will navigate through the operational steps required to gauge the pull-out force by implementing different types of epoxy resin. A significant aspect of this study, inspired by the work of Ghana (1990), revolves around devising a test method designed to generate realistic bond stresses.

2. Methodology

This research endeavors to evaluate the effectiveness of epoxy resin adhesives for affixing structural components such as beams, columns, slabs, and stairs within pre-existing frameworks. Utilizing the Standard Test Method for Bond Strength of Epoxy Resin Systems Used with Concrete, according to (ASTM 882-78, 1983) standards, this analysis will navigate through the operational steps required to gauge the pull-out force by implementing different types of epoxy resin. A significant aspect of this study, inspired by the work of Ghana (1990), revolves around devising a test method designed to generate realistic bond stresses.

2.1. Pullout Test

The bond strength of bars in a confined material can be evaluated based on research conducted by Guadagnini et al. In their study, the bond strength between concrete and fiber- reinforced polymer (FRP) bars were investigated using two testing methods: pullout and splitting/eccentric pullout methods. The tests were conducted by ASTM D6706, which provides guidelines for the direct testing of reinforcement and pullout forces.

2.1.1 The following epoxy resin selected are

Araldite (Rapid Curing), 4-Minute (AB Adhesive), and HILTI-100 Adhesive are among the materials considered. Nine steel molds, each measuring 150mm x 150mm, will be used for casting concrete samples to test various epoxy resin formulations."

- **Reinforcements used are:** High yield strength reinforcements needed are 10mm, 12mm, and 16 mm diameter reinforcements respectively 500mm length for each of the tree samples respectively fine aggregate sand coarse aggregate like granite Binder like 70k of cement.
- **Water:** for mixing fine and coarse aggregate.

- **Equipment and tools:** drilling machine, cutting machine, jig attachment and universal testing machine, bench vice, hack saw.
- **Measuring tools:** Vernier caliper, steel tape.
- **Selected resin adhesives are:** Araldite, AB-4minutes, and Hilti RE 100. It should be noted that the control specimen, epoxy RE 100 can give bond strength ranging between 17.5Mpa to 53 Mpa.

2.1.2 Procedure

- Cubes of varying concrete grades, including C20, C25, and C30, were produced with dimensions of 150mm by 150mm.
- Each concrete cube was drilled at the center, and the resulting dust was blown off.
- Inject epoxy resin into the drilled hole and allow it to cure.
- A jig attachment is a metal mold specifically designed to hold the concrete cube during the pullout test. The pullout force is applied to the embedded bar, causing the reinforcing bar to stretch until it is pulled out from the cube on the universal testing machine.
- Measure the pullout force and calculate the bond stress.

2.2. Production of Cube Concretes

The production of freshly prepared concrete encompasses critical stages such as batching and mixing, utilizing a prescribed weight mix ratio of 1:1½:3 alongside a water- cement ratio of 0.5. Essential materials including river sand, cement, and granite aggregates were thoroughly mixed in a concrete mixer to achieve a homogenous mixture. Following the mixing process, the resultant concrete mixture was carefully dispensed into molds, each dimensioned at 150 x 150 x 150mm, ensuring uniformity across samples. This meticulous procedure was systematically replicated for different concrete grades, specifically C20, C25, and C30, adhering to the consistent mold size of 150 x 150 x 150mm for each variant. This standardized approach facilitates the comparative analysis of concrete properties across varying strength grades, contributing to the understanding of how mix ratios and concrete grades influence the overall quality and performance of the concrete.

2.3. Compressive Strength Test

The evaluation of the concrete cube samples' strength was meticulously conducted using a compression testing machine, an apparatus extensively utilized for measuring concrete strength in alignment with the standards outlined in BS EN 12390-3: 2002. This process involved subjecting each specimen to a progressively increasing load until the point of failure, which was notably marked by the occurrence of cracking within the cube structure. The peak load sustained by each specimen before failure was diligently recorded, and for each designated concrete grade, an average value was computed. This average was determined by considering the specific curing method applied and the duration over which the samples were cured. This systematic approach to assessing concrete strength enables a comprehensive understanding of how different curing practices and timeframes influence the structural integrity and performance of concrete, thereby facilitating informed decisions in the construction and materials engineering fields.

Figure 1 Compressive strength Test

Figure 2 Marking of the Centre of Cubes Samples and Drilling of Embedment Length, Measuring of Internal and External Diameter respectively

Figure 3 Samples of Araldite and AB 4minutes adhesive

Figure 4 Hilti RE100 Sample

Figure 5 Application of Hilti RE100 Adhesive for Embedding Rebars into the Concrete Cubes

2.4. Pull-Out Test

The investigation into the pull-out behavior of rebar connections post-installed using chemical adhesives, notably epoxy resins, was conducted on concrete cube samples ranging from grade 20 to 30. This study meticulously documented the process of rebar installation, which involved applying epoxy resin adhesives onto the surface of the steel bars before their insertion into the concrete cubes. The length of rebar embedded within the cubes was adjusted according to the diameter of the bar, with the experiment utilizing rebar sizes of 10mm, 12mm, and 16mm. To facilitate optimal adhesive bonding and interaction with the concrete surface, the diameter of the holes drilled for each bar was designed to exceed the bar sizes by 2mm.

This research, as presented in the Journal of (King Saud University - Engineering Sciences 2017), delves into the nuanced pull-out behavior of rebars anchored in concrete through chemical adhesives and cement-based binders. The study's approach underscores the critical role of adhesive properties, rebar diameter, and drilled hole dimensions in influencing the efficacy of post-installation rebar connections within concrete structures. By examining these variables, the research contributes valuable insights into optimizing the performance and reliability of rebar anchoring systems in reinforced concrete applications.

2.4.1 The description of the jig attachment

The construction of a rectangular mold involved the use of 6mm thick sheet metal, resulting in a mold with dimensions of 150mm x 155mm x 155mm. To enclose the mold, a top metal sheet was fabricated to fit the rectangular opening precisely. To secure this top cover to the base of the metal mold, two opposite sides of the top metal sheet were drilled with eight holes, each 20mm in diameter, spaced 15mm apart. The assembly was designed to be fastened together using 19mm bolts and corresponding washers, ensuring a tight and secure fit between the top cover and the base plate of the mold.

A reinforcing bar with a diameter of 25mm was integrated into the mold design by welding it vertically to the base metal plate. This setup was specifically engineered for testing within a universal testing machine, where the bottom end of the reinforcing bar would be positioned within the machine's lower jaw, and the top end would be clamped by the upper jaw. This arrangement facilitates precise and controlled application of tensile or compressive forces to the embedded reinforcing bar during testing, allowing for the accurate assessment of the material's mechanical properties and the efficacy of the mold design in simulating real-world construction conditions.

Figure 6a Inserted rebars in the concrete cubes

Figure 6b Jig attachment and its parts

Figure 6c The pullout set-up on the universal testing machine

Figure 6d Inserted rebars in the concrete cubes

Figure 7 Sample of Column Drillied to Insert New Be

Table 1 Bond Stress Calculation

Determination of bond stress in reinforced concrete	**Symbol**	**values**	**Unit**
External Diameter	d=	11.3	Mm
Embedded Length	l==	60	Mm
Pullout Area	A= πdl	20106.19	mm^2
Bond Area	A2= πr^2	100.3	mm^2
Pullout force	P=	32600	N
Bond stress	σ=	Pullout Force Pullout/ Total Area	
			32600/20206.49
	σ=	15.3	N/mm^2

Table 2 The Pullout and Bond Stress Test Results for AB 4minutes Adhesive Samples

Parameters;	**Concrete grade, C**		
At Rd=9.3mm d=11.3mm l=60mm	**C20**	**C25**	**C30**
Pullout force, P(kN)	14.88	15.14	22.66
Bond Stress, σ (N/mm^2)	6.67	6.78	10.90
At Rd=11.40mm, d=13.40mm, l=70mm	**C20**	**C25**	**C30**
Pullout force, P(kN)	15.18	15.33	24.45
Bond Stress, σ (N/mm^2)	4.92	4.96	7.92
At Rd=15.2mm, d=17.2mm, l=90mm			

Pullout force, P(kN)	24.53	24.92	30.48
Bond Stress, σ (N/mm^2)	4.81 N/mm^2	4.89 N/mm^2	5.98 N/mm^2

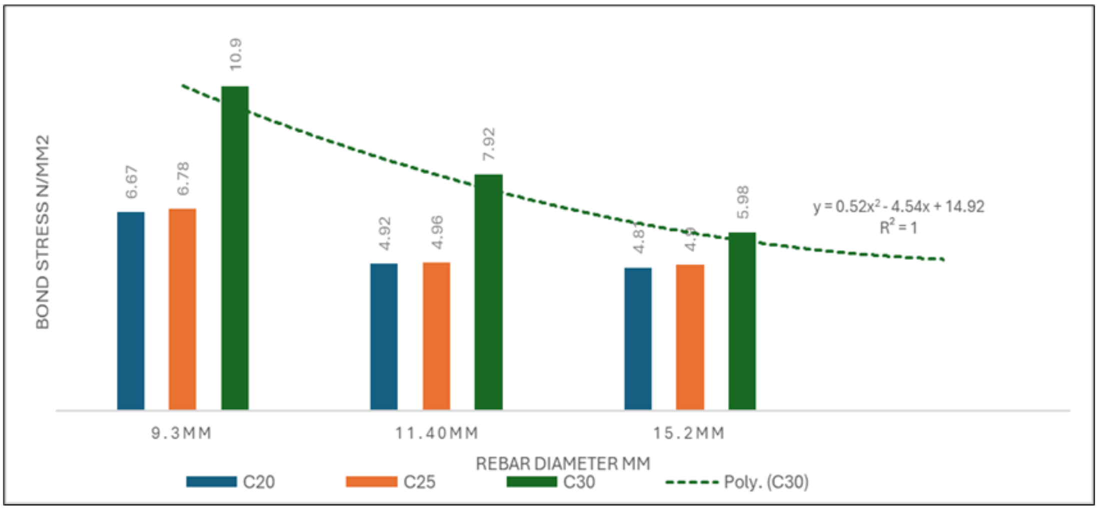

Figure 8 Bond Stress against Rebar Diameter for AB 4 minutes Adhesive samples

Table 3 the pullout and bond stress test results for ab 4minutes adhesive having 10.9 N/mm^2 samples while

At Rd=9.46mm d=11.5mm l=60mm	**C20**	**C25**	**C30**
Pullout force, P(KN)	17.37kN	19.78kN	27.32kN
Bond Stress, σ (N/mm^2)	7.65	8.71	12.03
At Rd=11.25mm, d=13.5mm, l=70mm			
Pullout force, P (kN)	20.21kN	22.83kN	29.90kN
Bond Stress, σ (N/mm^2)	6.49	7.34	9.61
At Rd=15.53mm, d=17.50mm l=90mm			
Pullout force, P (kN)	29.17kN	31.24kN	35.43kN
Bond Stress, σ (N/mm^2)	5.62 N/mm^2	6.02 N/mm^2	6.83 N/mm^2

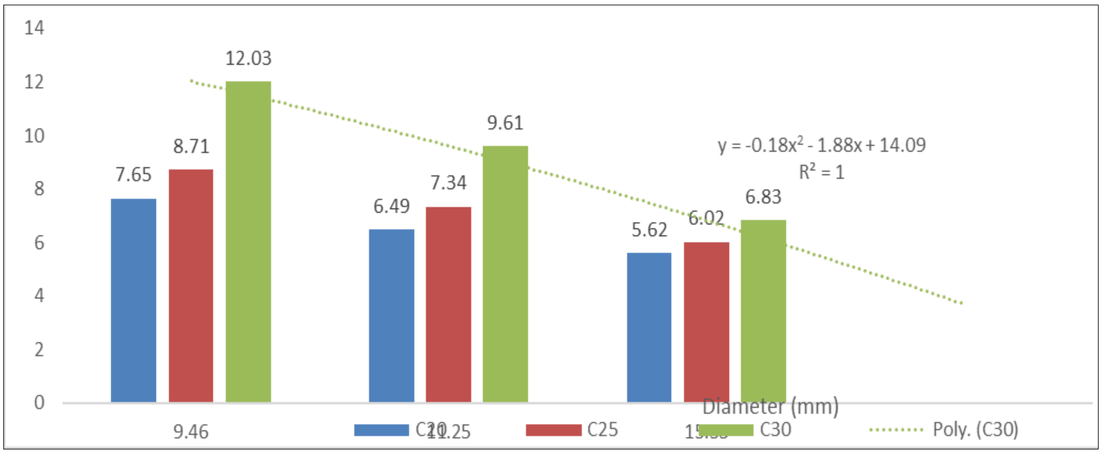

Figure 9 Bond Stress (σ) at different concrete grades, Araldite Adhesives Samples

Table 3; Illustrates the pullout and bond stress test results for araldite adhesive sample with highest bond stress of 12.03 N/mm^2 while Table 2: showing Bond Stress (σ) at different concrete grades, Araldite Samples Adhesives having highest at maximum concrete grade of C30. While Figure 10 showing bond stress (σ) at different concrete grades for Araldite adhesive.

Table 4 The Pullout and Bond Stress Results for Hilti RE100 Adhesive Samples.

At Rd=9.46mm d=11.5mm l=60mm	**C20**	**C25**	**C30**
Pullout force, P (kN)	51.20 kN	61.71 kN	63.69 kN
Bond Stress, σ (N/mm^2)	22.54	27.17	28.04
At Rd=11.3mm, d=13.6mm, l=70mm			
Pullout force, P (kN)	40.86 kN	55.64 kN	59.29 kN
Bond Stress, σ (N/mm^2)	13.03	17.74	18.91
At Rd=15.5mm, d=17.8mm, l=90mm			
Pullout force, P (kN)	30.54 kN	43.71 kN	45.88kN
Bond Stress, σ (N/mm^2)	5.78 Nm^2	8.28 N/mm^2	8.69 N/mm^2

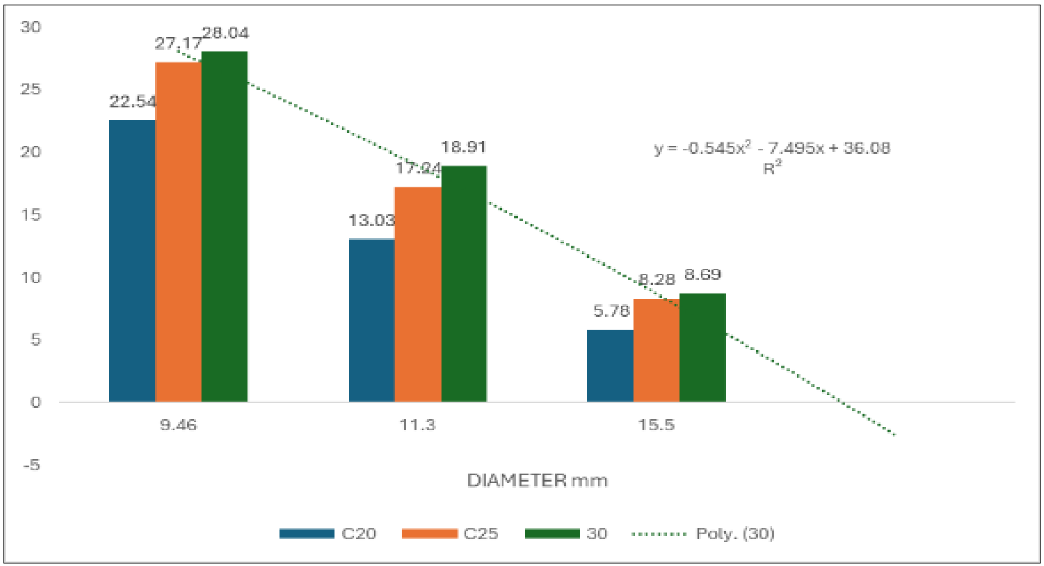

Figure 10 Bond Stress Versus Rebar Diameter with Hilti RE100

Table 4, showing the pullout and bond stress results for hilti re100 adhesive samples showing 28.04 N/mm^2 as highest at concrete grade 30 while graph 3, showing bond stress versus rebar diameter with Hilti RE100.

Table 5 is showing the comparative bond strength that was achieved for AB 4minutes, Araldite and Hilti RE100 for 10mm, 12mm and 16mm respectively.

Table 5 The summary of bond Stress of C30 Sample

Reinforcing steel diameter	**10mm**	**12mm**	**16mm**
AB 4minutes	10.02	7.94	5.99
Araldite	12.07	9.71	6.96
Hilti RE100	28.15	19.26	11.59

3. Discussion of Test Results

Relationship between bond stress and rebar diameter at different concrete grades. The findings from the bond tests, as summarized in Table 4.5, revealed a notable trend in the relationship between bond stress and reinforcing bar diameter. Through the application of the bond stress equation and the utilization of a dedicated spreadsheet for efficient calculations, the study elucidated a consistent pattern: as the diameter of the reinforcing bar increases, there is a corresponding decrease in bond stress within the concrete matrix. This inverse relationship between bond stress and bar diameter signifies that larger diameter reinforcing bars result in reduced bond stress when anchored in the concrete matrix. This observation aligns with prior research conducted by scholars such as (Tugrul Tunc et al. 2021) and (Rakesh Siempu and Rathish Pancharathi 2018), corroborating the consensus within the academic community regarding this phenomenon.

The influence of concrete grade on bond strength is highlighted, indicating an increase in bond stress with higher concrete grades. This observation underscores the significance of concrete compressive strength in facilitating effective bonding of new structural elements, with low-strength concrete potentially hindering optimal bonding. The study by (Gesoglu et al. 2005) further supports this notion by investigating the tensile behavior of post- installed anchors in varying concrete strengths, revealing a positive correlation between concrete strength and anchor capacity.

When examining the relationship between bond stress in concrete with and without adhesive application, the importance of adhesive selection and surface preparation becomes apparent. (Zilch and Pfeiffer's 2011) research elucidates how adhesives enhance bond strength by filling voids, facilitating better contact, and offering chemical bonding or surface interactions with the concrete substrate. Proper surface cleaning and roughening are crucial for optimizing adhesion and bond strength.

The effect of embedded length on pullout force and bond stress is noted, with longer embedded lengths generally resulting in increased pullout force and reduced bond stress. (Salim et al.'s 2022) findings corroborate this trend, highlighting the significance of embedded length in determining pullout force, albeit without specific bond stress calculations. Overall, these studies provide valuable insights into the multifaceted factors influencing bond stress in concrete structures, emphasizing the importance of concrete grade, adhesive selection, surface preparation, and reinforcement characteristics in optimizing bond performance and structural integrity.

4. Conclusion

Cost effectiveness; as the primary aim of design philosophy is having a safe and economical structure is the ultimate goal. The cost-effectiveness describe as;

AB 4minutes adhesive cost #800 for the two sachet and its gives average 10N/mm2 bond stress which is #80 per unit bond stress in N/mm2 at C30 samples and minimum pullout force is 18N/#.

Araldite adhesive cost the sum of #3500 for the mixture of the two sachets applied and it gives an average 12.60N/mm2 which is which is #277.78 per unit bond stress in N/mm2 at C30 samples and the minimum pullout force is 5N/#.

Hilti RE100 is a globally recognized epoxy resin adhesive that costs #29,500 for a bottle when applied and it gives an average 28.04N/mm2 which is #1,052.07 per unit bond stress in N/mm2 at C30 samples and the minimum pullout force is 1.1N/#.

Therefore, AB 4 minutes is the cheapest of the three examined adhesives and Araldite is slightly expensive while Hilti RE100 is more expensive and relatively scarce unlike AB 4 minutes and Araldite as they are readily available and cheaper.

The use of epoxy adhesive for post-installation applications offers numerous advantages, particularly in situations where modifications to the initial structural design are necessary or where expansion of the existing structure is required. Epoxy adhesives provide strong and durable bonding, allowing for secure attachment of new structural elements to the existing concrete substrate. These findings elaborate the influence of embedded length and concrete grade on bond strength highlight important considerations in reinforcement design and construction. Increasing the embedded length can enhance pullout force, thereby improving the overall bond strength between reinforcements and concrete. Additionally, variations in concrete grade can impact the bond stress of epoxy adhesives, underscoring the importance of selecting the appropriate adhesive for specific concrete grades and structural requirements.

Overall, the adoption of epoxy adhesive for post-installation applications, coupled with a thorough understanding of bond strength through pullout tests, contributes to the creation of reliable and durable structures capable of withstanding diverse loads and environmental conditions.

Recommendation

Based on the findings of this research, the following recommendations were made

- Optimal Embedded Length: It is recommended to use an embedded length of 5 times the diameter (5D) of the reinforcing bar for post-installation applications. This length showed evidence of increasing pullout force, indicating improved bond strength compared to shorter embedded lengths.
- Higher Concrete Grade: To optimize the bonding of reinforcing bars, it is advisable to use higher concrete grades rather than lower ones. The research suggests that each epoxy resin sample exhibited the highest bond stress at concrete grade 30, indicating better bonding performance with higher-grade concrete.
- Rebar Diameter Selection: Considering the observed reduction in bond stress with increasing diameter of the reinforcing bar, it is recommended to use lower rebar diameters when selecting materials for post-installation of structural elements. This choice can help maintain adequate bond strength between the reinforcement and the concrete.
- Economical Adhesive Selection: Araldite adhesive is recommended for retrofitting purposes due to its cost-effectiveness while still providing structurally sufficient bond stress similar to Hilti RE100 adhesive. This choice offers a balance between cost efficiency and performance.
- Consideration of Alternative Adhesives: Given the close range of bond stress between Araldite and Hilti RE100 adhesives, Araldite can be considered a viable alternative to Hilti RE100, especially considering its slightly lower pullout force. This recommendation allows for flexibility in adhesive selection while ensuring

Compliance with ethical standards

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Disclosure of conflict of interest

The authors Damilare Emmanuel Hassan, John Oluwole Labiran and Olumide Joseph Ajayi thereby disclosed that there is no conflict of interest during the research work. All experiment undergone professional scrutiny.

Conceptualization: Hassan D.E and Labiran J.O, Methodology; Hassan D.E and Labiran J.O, Formal analysis: Ajayi O.J and Hassan D.E, Investigation; Hassan D.E, writing original draft preparation by Hassan D.E and Labiran J.O, Editing by Hassan D.E and Ajayi O.J

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