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Effect of Corrosion Concrete Repair on Flexural Strength by Grouting and Jacketing Methods

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Abstract

One of the problems in reinforced concrete construction is steel corrosion. Corrosion causes a reduction in the flexural strength of building structures. Therefore, structural repairs are very important to restore the strength of the building. The mortar grouting and jacketing methods are methods that are relatively easy to apply. The grouting method is applied by injecting and filling cracks in corroded concrete. Meanwhile, the jacketing method is carried out by covering the old corroded concrete with a layer of new concrete. This research used 15 specimens of reinforced concrete (RC) with a compressive strength of 30 MPa. Design corrosion levels of 20%, 25%, and 30% were obtained from accelerated corrosion using a DC Power Supply and 5% NaCl solution. The research results showed that the grouting repair method was able to increase the flexural strength of corroded reinforced concrete by up to 4.77%, and the jacketing method by 13.81%. However, the flexural strength value will decrease as the corrosion levels increases.

1. Introduction

Along with population growth, construction development in Indonesia is very rapid, especially in big cities. Strong and sturdy buildings are needed to support this development [1]. Concrete is a material often used for constructing buildings, bridges, or other infrastructure because concrete is resistant to fire and has compressive and flexural strength, especially in reinforced concrete (RC) [2]. Concrete has a large compressive strength while its tensile strength is small, while to create a good building structure, the compressive and tensile strength of the concrete must be large [3], [4]. Therefore, concrete always has steel reinforcement added to support good structural performance [5]. Almost all buildings in Indonesia use concrete, especially RC, in their building materials. Steel reinforcement in concrete can strengthen the structure of the building, but steel is very susceptible to chemical elements that cause reinforced concrete to experience corrosion [6]. One of the problems with using reinforced concrete is corrosion [7]. Corrosion is one of the big enemies in the industrial world [8], [9]. Some examples of losses caused by corrosion are a decrease in material strength and repair costs, which will increase much more than expected [10]. So, preventive measures are needed against corrosion attacks [11]. According to Ma et al. [12], corrosion in RC can occur due to two things: the intrusion of chloride ions and carbonation. Poor compaction when making concrete can also cause the reinforcement to corrode. The gaps between the aggregates can increase the acceleration of chemical elements entering the concrete, thereby speeding up the corrosion process [13], [14]. Corrosion is a problem in building structures that needs to be addressed. One effort before repairing corrosion in reinforced concrete is to find out if there is corrosion in the concrete reinforcement [15]. So, we can estimate the effective concrete repair method that can extend the concrete's life and strengthen the concrete's flexural strength [16].

Repair and maintenance of concrete with corroded reinforcement must be made to maintain the structural strength of the RC. One of the damages experienced when the reinforcement in the concrete corrodes is the occurrence of cracks [10]. The increase in volume due to rust in the corroded steel reinforcement causes the concrete and concrete cover to crack [15], [17], [18]. Some efforts to repair or repair corroded concrete are by grouting and jacketing [19]. Grouting is a method used to repair porous concrete with exposed reinforcement. The porous concrete is chipped, and the inlet and outlet pipes are planted in the porous area to cover the porous surface with concrete that hardens quickly [20], [21]. Initial testing was carried out on hardened concrete with water as a grouting material for cleaning and determining the level of leaks. Grouting is carried out with a grouting material suitable for a certain pressure, and after completion, the inlet and outlet pipes are cut, and then the concrete face is repaired with mortar [22]. One method of repairing corrosion in concrete is the jacketing method. This method can strengthen the concrete structure by increasing the volume or dimensions of the concrete [23]. Very limited research has been carried out regarding the repair of corroded concrete using grouting and jacketing methods, such as by Thanoon et al. [24], and Sudha et al. [25]. However, this research focuses on repairs addressing damage caused by loading rather than corrosion. Therefore, it emphasizes the significance of investigating repairs using grouting and jacketing specifically for corrosion-induced damage. So, in this research the effect of concrete repair using corroded grouting and jacketing methods on the flexural strength of concrete will be analyzed. Apart from that, this research will also present an analysis related to ductility values, stiffness, and the relationship between flexural strength values for grouting and jacketing methods. It is hoped that the results of this research can become a reference for the best repair methods used in the structural strengthening process, especially to increase the flexural strength of corroded concrete.

2. Materials and Methods

2.1 Materials

This study used 15 reinforced concrete specimens with 150 x 150 x 620 mm^3 in dimensions. The concrete is designed to have a compressive strength of 30 MPa and a concrete cover thickness of 20 mm. The mix design used in this research refers to ACI regulations 211.1-91 [26] concerning Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. Curing is carried out by immersing in normal water for 28 days [27]. The sand comes from Kulon Progo, Yogyakarta, which passes filter No. 4 (4.75 mm) and is retained on sieve No. 200 (0.075 mm) [28]. The gravel comes from Merapi, Yogyakarta, with the criteria of being hard, non-porous, not containing clay, and having a maximum diameter of 20 mm [29]. The cement used in this research is Portland cement type I [30]. The reinforcement uses plain reinforcement with a diameter of 8 mm as the main reinforcement and reinforcement with a diameter of 6 mm as stirrups [31]. The proportion of mix design per m^3 is 7.853 Kg of cement, 16.738 Kg of coarse aggregate, 12.915 Kg of fine aggregate, and 3.042 Liter of water. Various material tests are carried out to maintain the quality of the concrete mix design as shown in Table 1. Meanwhile the detailed reinforcement scheme for the specimen is shown in Fig. 1.

Table 1 *Fine and coarse aggregate test data*

Material test type	Fine aggregate	Coarse aggregate	Unit
Fine modulus	2.389	-	-
Mud content	1.71	1.59	%
Water absorbtion	1.21	1.0	%
Bulk specific gravity	2.64	2.619	-
Saturated surface dry specific gravity	2.71	2.681	-
Apparent specific gravity	2.71	2.723	-
Abrasion	-	23	%

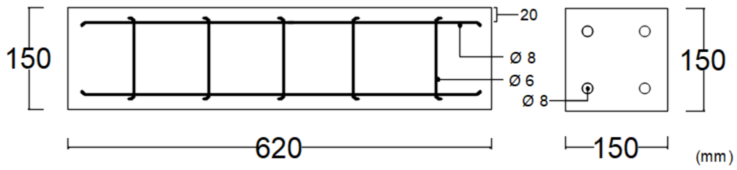

Fig. 1 *Dimension of the specimens*

2.2 Corrosion Acceleration Process

The corrosion acceleration process is carried out after the concrete has cured for 28 days. The corrosion acceleration process is carried out with the help of DC Power Supply as a medium for the accelerator and distribution of electric current [32]. The positive pole has a cable attached to the concrete reinforcement, while the negative pole has a cable connected to the reinforcement submerged in a saltwater solution [18]. The solution is an electrolyte solution of 5% NaCl, with 20%, 25% and 30% corrosion levels. Using tools with currents of 3 A and 5 A. Mass loss in the reinforcement is determined using Faraday's Law [4]. Corrosion of concrete reinforcement is carried out in a styrofoam box filled with water with a 5% NaCl solution. The corrosion acceleration site is a styrofoam box measuring 740 x 400 x 150 mm^3 filled with water and 2.3 kilograms of NaCl. The acceleration corrosion scheme is shown in Fig. 2.

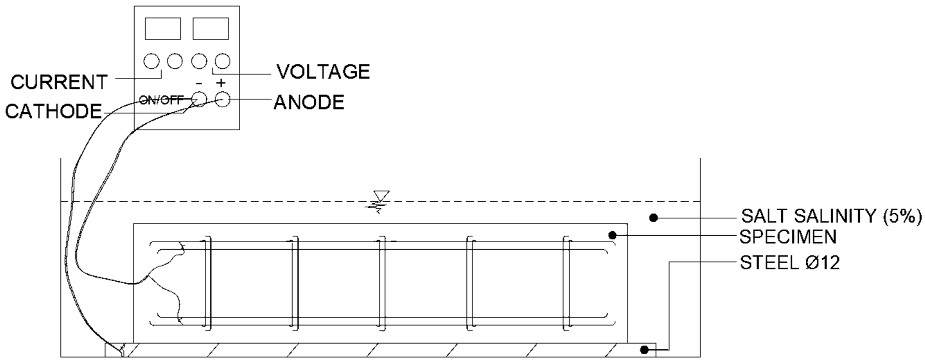

Fig. 2 *Acceleration corrosion scheme*

2.3 Repair Grouting Method

The porous parts are grouted using Pointing Brick Grouting to cover the porous surface. After the repair is complete, the concrete surface is coated with mortar. In the improved grouting method, the design compressive strength of mortar is greater than concrete compressive strength design, namely 45 MPa. While the ingredients mortar mixed are Portland cement, fine aggregate, and water in a ratio of 1:3:0.5. Before starting the repair grouting process, the test object that has hairline cracks is drilled or damaged by chiseling along the crack. After being drilled to a depth of 10 mm, it is then applied with Bonding Adhesive mixed with water and cement in a ratio of 1:1:2. Then the repair mortar material is injected using point brick grouting with the help of pouring using a trowel. The grouting method process can be seen in Fig. 3.

Fig. 3 *Grouting process*

2.4 Jacketing Repair Method

The Jacketing method for repairing corroded reinforced concrete at this stage involves adding dimensions to the concrete by thickening the concrete blanket to 20 mm thick using formwork larger than the specimen. The mixture used in this method is Portland cement, fine aggregate, and water in a ratio of 1:3:0.5. A depiction of the jacketing repair process is shown in Fig. 4. Specimens damaged due to corrosion and loading before starting the jacketing repair process. The surface of the specimen is cut using a grinding machine. The old concrete is cut so that the mortar for the repair material adheres more strongly to the old concrete. This can be found in the interlocking or locking system so that they are interlocked and connected so that the movement of one part will depend on another. After being cut to a depth of 0.2 mm, the surface of the concrete is then smeared with Bonding Adhesive mixed with water and cement in a ratio of 1:1:2. Then it is inserted into the new formwork with dimensions of 640 x 170 x 170 mm^3 which is then cast using repair mortar.

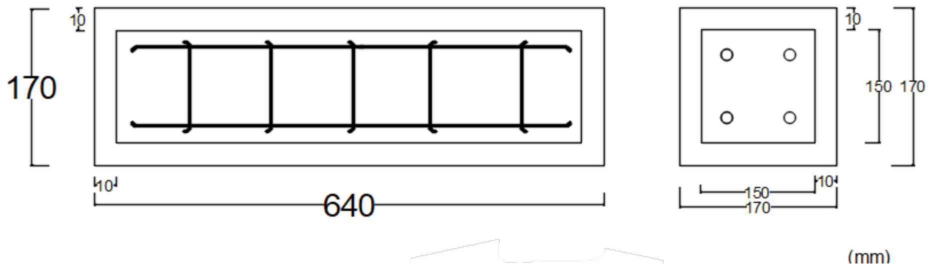

Fig. 4 *Jacketing method repair scheme*

2.5 Concrete Mechanical Properties Testing

Mechanical testing of concrete properties includes flexural strength, ductility, and stiffness of concrete using a Universal Testing Machine (UTM) after the corrosion process is complete. Concrete flexural strength testing is carried out in the test method using a four-point bending test [33]. Concrete flexural strength testing was carried out several times on different test objects. The first specimen that has gone through the accelerated corrosion process is subjected to a flexural strength test to obtain the strength value of the specimen before repair.

3. Result and Discussion

3.1 Corrosion Acceleration Test Result

Corrosion of concrete reinforcement is carried out in a 5% NaCl solution. The percentage (%) of corrosion on each specimen is 20%, 25%, and 30%, which is calculated based on time and reduction in weight of the reinforcement. Accelerated corrosion causes rusting of the reinforcement, which causes cracks on the concrete surface, which will later be repaired. Corrosion acceleration results can be seen in Fig. 5. The planned corrosion percentages in accelerated corrosion are 20%, 25%, and 30%. The difference in percent mass loss for all specimens was 0.1% to 1.4% higher or lower than the corrosion target. The average actual corrosion level was found to be 20%, 25%, and 30% at the level of each specimen variation. The difference in the planned and actual corrosion levels is caused by the amperage of the DC Power Supply, which changes instantly depending on the electric current at the main socket.

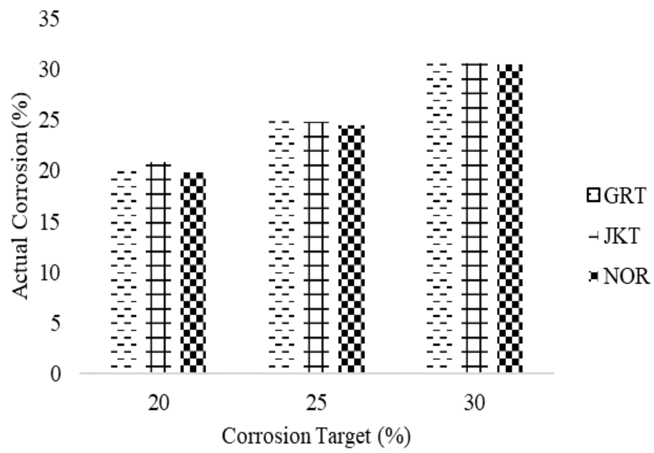

Fig. 5 *Corrosion acceleration results*

3.2 Flexural Strength of Grouting Method

After the corrosion acceleration and repair processes have been completed, the flexural strength test is carried out. Flexural strength uses two loading points to obtain maximum load results and flexural strength. The results of testing the flexural strength of repair specimens using the grouting method are shown in Fig. 6. Based on testing the flexural strength of the specimen using the grouting repair method, the largest result was 3.93 MPa on the GRT 20A test object with an actual corrosion rate of 19.3%. Meanwhile, the smallest flexural strength value, namely 3.14 MPa, was obtained from the GRT 30B specimen at an actual corrosion level of 30.3%. The results show that when the actual corrosion percentage is higher, the bending strength gain is smaller. This is because concrete reinforcement corrosion can reduce the concrete's strength and quality. According to Kearsley & Joyce [34] the bond between steel and concrete and concrete will degrade and weaken when it loses its mass, while corrosion causes a reduction in the mass of the reinforcing steel.

The existence of grouting improvements can restore the initial flexural strength. This can be proven in normal concrete 20, 25, and 30 with actual corrosion levels of 20%, 24.5%, and 30.5%, resulting in flexural strengths of 3.58 MPa, 3.53 MPa, and 3.23 MPa. Meanwhile, the average flexural strength of test objects with the same level of corrosion when repair grouting was carried out at GRT 20 (20.13%), GRT 25 (25.4%), and GRT 30 (30.73%) was 3.88 MPa, 3.75 MPa, and 3.25 MPa or larger than normal concrete without repair. The decrease in the flexural strength of concrete when the percentage of actual corrosion increases can be seen in the graph in Fig. 6. Based on the conclusions, the flexural strength of concrete increases by 4.77% when it is repaired using the grouting method. However, this grouting technique has limitations as it relies on a single method. Nonetheless, these results can serve as a foundation and example for other grouting techniques. Therefore, it is essential to develop alternative grouting techniques and superior mortar materials to achieve more extensive and profound outcomes.

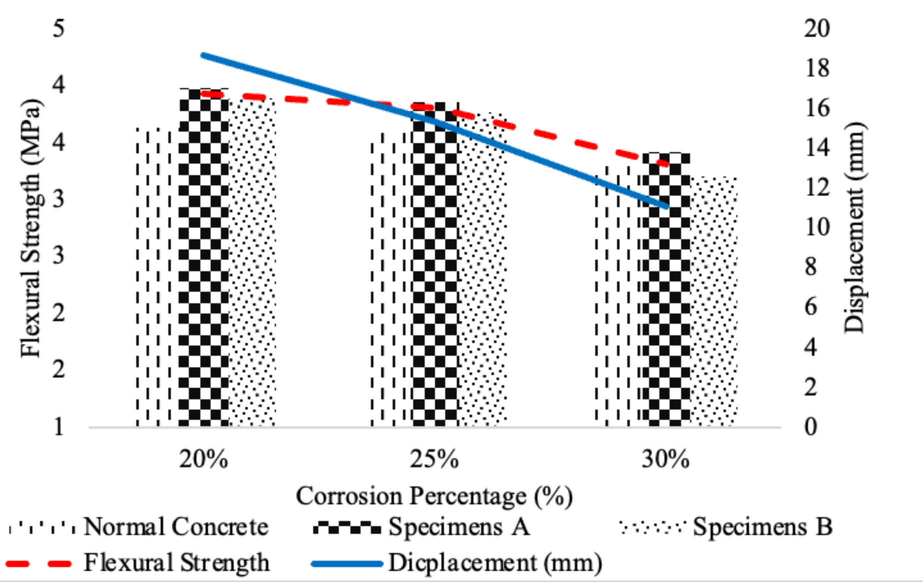

Fig. 6 *Graph of the relationship between grouting flexural strength and corrosion level*

3.3 Flexural Strength of Jacketing Method

The same thing happened to the grouting method specimen. The flexural strength test is carried out in the jacketing method. Flexural strength uses two loading points to obtain maximum load results and flexural strength. The results of testing the flexural strength of repair specimens using the jacketing method are shown in Fig. 7. Based on testing the flexural strength of the specimen using the jacketing repair method, the largest result was 4.15 MPa on the JKT 20B specimen with an actual corrosion rate of 21.3%. Meanwhile, the smallest flexural strength value, namely 3.28 MPa, was obtained from the JKT 30B specimen at an actual corrosion level of 29.9%. The results show that when the actual corrosion percentage is higher, the bending strength gain is smaller. This is because concrete reinforcement corrosion can reduce the concrete's strength and quality. According to Kearsley & Joyce [34] the bond between steel and concrete and concrete will degrade and weaken when it loses its mass, while corrosion causes a reduction in the mass of the reinforcing steel.

Improved jacketing can increase flexural strength. This can be proven in normal concrete 20, 25, and 30 with corrosion levels of 20%, 24.5%, and 30.5%, resulting in flexural strengths of 3.58 MPa, 3.53 MPa, and 3.23 MPa. Meanwhile, the average flexural strength of specimens with the same level of corrosion when repairing jacketing JKT 20 (20.97%), JKT 25 (24.9%), and JKT 30 (30.67%) is 4.41 MPa, 3.98 MPa, and 3.62 MPa or larger than normal concrete without repair. The decrease in concrete flexural strength when the corrosion percentage increases can be seen in the graph in Fig. 7. Based on the conclusions, the flexural strength of concrete increases by 13.81% when it is repaired using the jacketing method. The jacketing technique used in this study does not involve the use of new reinforcement to cover the old beam, which is a limitation. However, the results demonstrate a simple method of using a mortar blanket to close gaps and improve the bending strength of the beam.

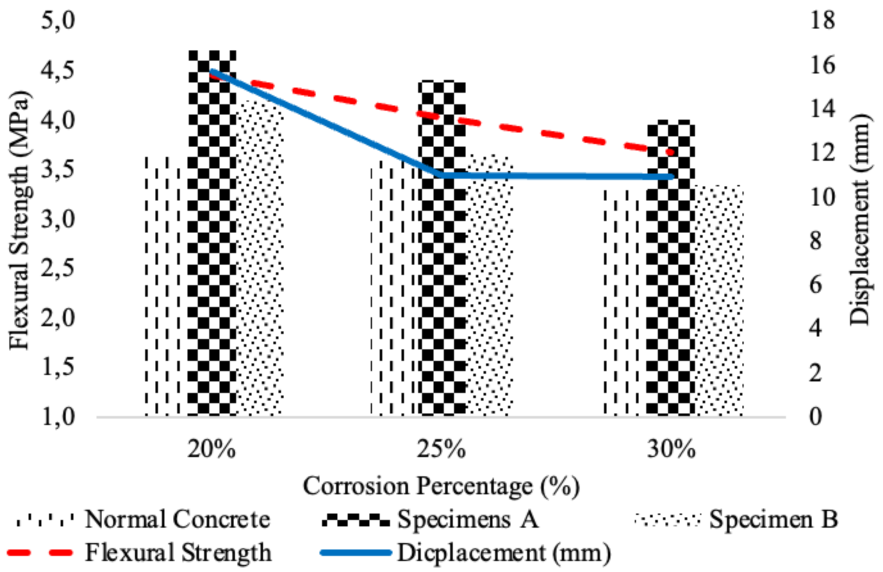

Fig. 7 *Graph of the relationship between jacketing flexural strength and corrosion level*

3.4 Flexural Strength Relationship between Grouting and Jacketing

The differences in repair methods were conducted to determine the differences in flexural strength values produced after and before the repair process. The grouting and jacketing repair methods obtained different results. The flexural strength of the grouting method is smaller than that of the jacketing method. Based on normal concrete with the same level of corrosion plan, the grouting method can restore the flexural strength to 4.77% of normal concrete. Meanwhile, based on normal concrete, the jacketing method can increase 13.81% more than normal concrete with the same level of corrosion but not repaired. The flexural strength graph can be seen in Fig. 8. Based on the results of the jacketing method, the flexural strength is superior to that of the grouting method, even with the additional support of a new concrete cover. However, it is unclear whether internal cracks caused by corrosion will be repaired as effectively as with the grouting method. Therefore, it is necessary to use concrete quality checking tools, such as scanning or Non-Destructive Test (NDT), to assess the concrete's condition internally.

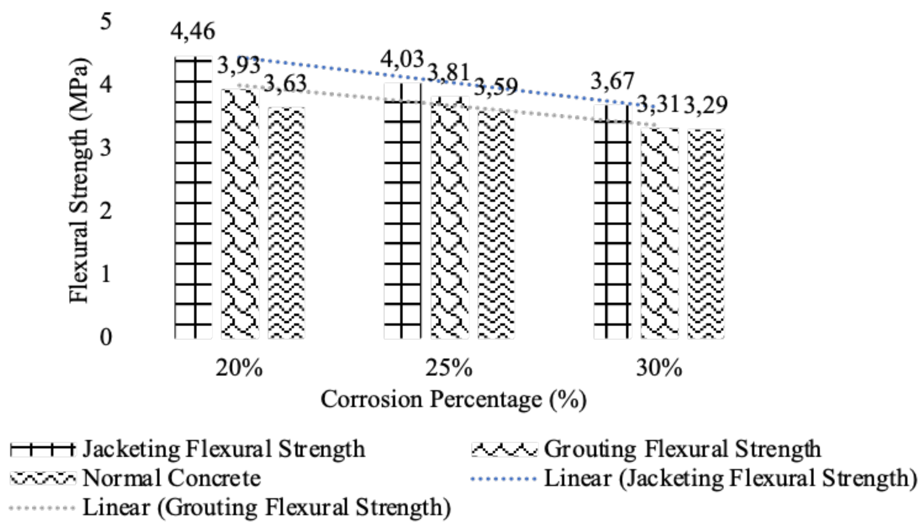

Fig. 8 *Graph of the relationship between repair grouting and jacketing on flexural strength*

3.5 Ductility

Ductility is the ability of a structure or sub-structure to withstand dominant inelastic deformations to prevent collapse. Mathematically, the ductility value of a structure is defined as the ratio between the maximum planned deformation and the deformation when the first yield occurs in the structure being tested [35]. Ductility is obtained from the division of displacement or ultimate and yield point. The relationship graph between ductility and actual corrosion can be seen in Fig. 9. The increasing percentage of actual corrosion causes a decrease in ductility in concrete. In repair test specimens with the same corrosion, there was an increase in control concrete, such as grouted concrete GRT 20B (6.38 mm) with normal concrete NOR 20 (3.56 mm), the same as with jacketing repairs. This is because corrosion of steel reinforcement can reduce flexible qualities such as ductility. When there is a reduction in the area and volume of steel, it can cause a decrease in the effectiveness of reinforcement and ductility in reinforced concrete [36]. The decrease in ductility value when the actual corrosion value increases in the improvement of grouting and jacketing methods can be seen in Fig. 9.

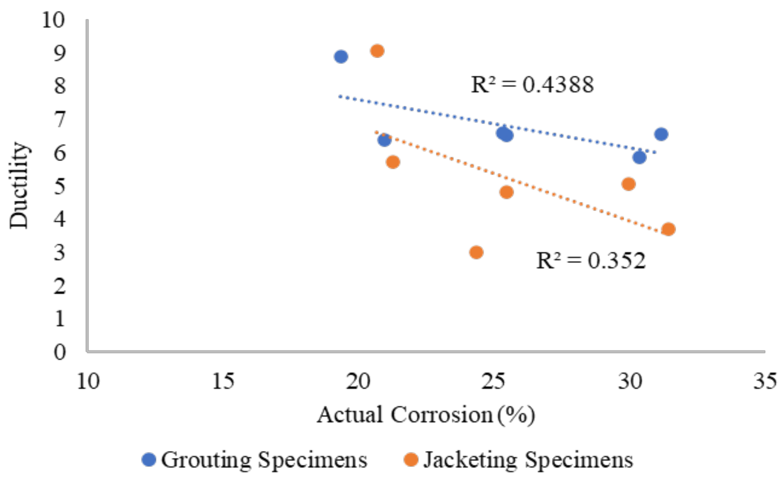

Fig. 9 *Graph of the ductility value of the specimen*

3.6 Stiffness

Stiffness is obtained by calculating the maximum force on bending strength in kilonewton units divided by the yield point. Beam stiffness is a function of the elastic modulus and moment of inertia. A beam that was originally not cracked and became cracked is evidence of structural stiffness in the beam [37]. The results of the stiffness relationship graph can be seen in Fig. 10.

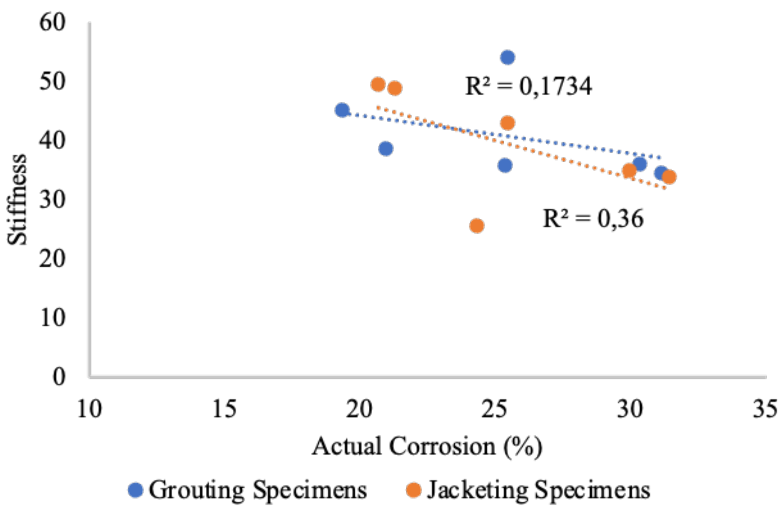

Fig. 10 *Graph of test object stiffness values*

The test specimen JKT 20A obtained a stiffness of 49.03 kN/mm, JKT 25A a stiffness of 43.03 kN/mm, and JKT 30A a stiffness of 34.01 kN/mm. This shows that JKT 30A, with the highest actual corrosion, obtained the smallest stiffness at the jacketing method. In the research of Zaki et al. [18], when concrete experiences a decrease in the bond between the reinforcing steel and concrete, this could be due to corrosion of the reinforcement, which reduces the ability of the concrete specimen to withstand loading. In the grouting and jacketing repair methods, both experienced a decrease with the same character, which was caused by an increase in the corrosion percentage. The average stiffness of the grouting method is greater than that of the jacketing method, with grouting 40.76 kN/mm and jacketing 39.36 kN/mm. So, the grouting and jacketing repair methods have a 3.42% difference in stiffness.

4. Conclusion

Based on the test results and analysis of experimental results in research regarding the effect of corrosion repair of concrete on flexural strength, several things can be concluded as follows:

- The results of flexural strength using the grouting repair method process decrease along with the increase in the actual corrosion level. The flexural strength results were found to be 4.77% greater than control concrete with the same level of corrosion.
- The results of flexural strength using the jacketing repair method process decrease along with the increase in the actual corrosion percentage. The flexural strength results were 13.81% greater than control concrete with the same level of corrosion.
- The results of flexural strength using the jacketing repair method process decrease along with the increase in the actual corrosion level. The jacketing flexural strength results were 13.81% greater than control concrete with the same level of corrosion. Meanwhile, grouting is 4.77%. In both repair methods, namely grouting and jacketing, better results were obtained in repair jacketing, namely 9.04% higher.
- The increasing percentage of actual corrosion causes a decrease in ductility and stiffness for all repair methods, both grouting and jacketing methods.
- The jacketing repair method is more effective in increasing the flexural strength, ductility and stiffness values of corroded concrete when compared to the grouting method.
- Further research is needed to compare multiple repair techniques and materials for more comprehensive results, as this study only focuses on one technique and one type of repair mortar.

Conflict of Interest

Authors declare no conflict of interests.

Author Contribution

Study conception and design: *Ahmad Zaki and Fadila Rizka Afifi;* ***methodology:*** *Ahmad Zaki and Fadila Rizka Afifi;* ***analysis and interpretation of results:*** *Ahmad Zaki, Fadila Rizka Afifi, Kharisma Wira Nindhita and Khairil Mahbubi;* ***draft manuscript preparation:*** *Kharisma Wira Nindhita and Khairil Mahbubi;* ***review and editing manuscript:*** *Ahmad Zaki, Kharisma Wira Nindhita and Khairil Mahbubi;* ***supervision:*** *Ahmad Zaki and Fadila Rizka Afifi. All authors reviewed the results and approved the final version of the manuscript.*

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