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THE EFFECT OF REINFORCING STEEL CORROSION ON THE ADHESIVE STRENGTH OF REINFORCED CONCRETE (CASE STUDY OF THE FACULTY OF VETENARY MEDICINE BUILDING, MUHAMMADIYAH UNIVERSITY OF WEST SUMATRA)

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Abstract. *The construction of the UM west Sumatera Faculty of Veterinary Medicine Building hasstopped until the column work which has left 1,5 meters of overstep reinforcement on each columnsince 2021. During the period, the reinforcement has experienced uniform corrosion along the length of the reinforcement which causes a reduction in the cross-sectional area of the steel reinforcement so that the bearing capacity of the steek will decrease. This study was conducted to compare the bond strength of concrete with corroded and uncorroded reinforcement before construction continued the building. Concrete specimens of K-250 size 15X15X15 equipped with D19 reinforcement were made for bond strength test at the age of 28 days. The result shows that the bond strength of the concrete with corroded reinforcing steel was quite low. So that beforethe construction is continued, the corrosion on the entire surface of the reinforcement must be peeled off first.*

Keywords: *Bond Strength; Corrosion; Reinforced Concrete*

1. INTRODUCTION

Concrete is a construction material that has a high compressive strength value and is weak in resisting tensile force. A combination of concrete and reinforcing steel is required to bear the tensile force arising from the working load. Reinforced concrete can work in bearing loads due to the strong adhesion factor between the concrete and the reinforcing surface. One of the causes of the weak adhesion system between concrete and rebar is corrosion. Corrosion on steel rebar in addition to causing a reduction in surface area also causes a volume of compounds resulting from corrosion reactions that is greater than the volume of reacting steel. This can cause the concrete covers to crack if this damage continues, then the concrete building is no longer suitable for use (Rasyid et al., 2021).

There are many construction projects whose work has stopped due to various things and on average the project has stopped working on columns made of reinforced concrete. The work on abandoned structures often allows reinforcing steel to be exposed to natural conditions continuously for a long time. Reinforcement steel that is exposed to natural conditions will undergo corrosion and if the reinforcement is cast immediately, it will have a bad impact on the performance of reinforced concrete, especially the performance of strong adhesion.

Based on previous research conducted by Arief Subakti Ariyanto, the impact of corroded reinforcing steel on construction is not only strong adhesion that is affected, the occurrence of corrosion in a building can affect the service life of the building, because the performance of building structural components decreases. To achieve the life of the building according to the plan, continuous maintenance of the building and maintenance of the building is required (Ariyanto, 2022).

The construction of the Faculty of Veterinary Medicine Building, Campus IV, University of Muhammadiyah West Sumatra is one example of a development project that has been stopped since 2021 so that the construction project leaves 1.5 meters of reinforcement in each column. The development project is a case study in this study that will outline how the effect of corrosion on reinforcing steel on the adhesion strength of reinforced concrete considering that reinforced concrete is the most important part of the building structure. This study will also compare the adhesion strength between reinforced concrete using corroded reinforcement steel and non-corroded reinforced concrete.

2. LITERATURE REVIEW

2.1 Reinforced Concrete Forming Materials

According to SNI 2847:2013 concrete is a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additives that form a solid mass. According to SNI 03-2847-2002, lightweight concrete is concrete that contains lightweight aggregate and has a specific gravity of not more than 1900 kg/m^3.

1. Cement

According to SNI 03-2847-2002 (Procedures for Calculating Concrete Structures for Buildings) several types of cement must meet several conditions to be able to become a concrete forming material.

- SNI 15-2049-1994, Portland cement.
- "Specification of hydrolyzed blended cement" (ASTM C 595), except for types S and SA which are not intended as the main binding elements of concrete structures.
- "Specification of expansive hydraulic cement" (ASTM C 845).

2. Aggregate

Aggregate is a granular material, such as sand, gravel, crushed stone, and incandescent furnace crust that is used together with a binding medium to build a concrete or hydraulic cement mixture (SNI - 03 - 2847 - 2002, n.d.). Aggregate for concrete must meet one of the following conditions:

- "Aggregate specifications for concrete" (ASTM C 33).
- SNI 03-2461-1991, Specification of lightweight aggregate for structural concrete.

The maximum nominal size of the coarse aggregate must not exceed:

1. 1/5 of the smallest distance between the sides of the mold,
2. 1/3 of the thickness of the floor slab,
3. 3/4 minimum net distance between rebar–reinforcement or wire–wire, rebar bundles, or prestressed tendons or sleeves.

3. Water

The water used in the concrete mixture must be clean and free of damaging materials containing oils, acids, alkalis, organic matter, or other materials that are detrimental to concrete or reinforcement. Mixing water used in prestressed concrete or on concrete embedded with aluminum metal, including free water contained in aggregates, must not contain harmful amounts of chloride ion (SNI - 03 - 2847 - 2002, n.d.). According to ASTM C 109, non-potable water should not be used as a concrete mixing agent unless it meets the following conditions:

- The selection of the proportion of concrete mixture should be based on the concrete mixture that uses water from the same source.
- The results of the 7- and 28-day age tests on mortar test cubes made from a water mixture are not potable and must have a strength equal to at least 90%

of the strength of the test piece. The comparison of such strength tests shall be carried out on similar mixtures except on the mixing water made and tested following the "Compressive strength test method for hydraulic cement mortars".

4. Reinforcing Steel

Based on SNI 03-2847-2002 (Procedures for Calculating Concrete Structures for Building Buildings), rebar is a plain or threaded or pipe-shaped steel bar that functions to withstand tensile force on concrete structural components, excluding prestressed tendons, unless specifically included. Threaded rebar steel (BJTD) must meet one of the following conditions :

- "Specification for threaded and plain billet steel bars for concrete reclamation" (ASTM A 615M).
- "Specifications for threaded and plain axle steel bars for concrete reclamation" (ASTM A 617M).
- "Specifications for low alloy threaded and plain steel for concrete reclamation" (ASTM A 706M).

2.1 Compressive Strength of Concrete

According to SNI 03-1974-1990, the compressive strength of concrete is the magnitude of the load per unit area, which causes the concrete test piece to be destroyed when loaded with a certain compressive force, which is generated by the pressing machine. The compressive strength of concrete identifies the quality of a structure, where the higher the level of structural strength desired, the higher the quality of the concrete produced (PB.1989:16). The compressive strength of concrete will increase with the increase in the age of concrete. In certain cases, the compressive strength of concrete will continue to increase until a few years later. Usually, the compressive strength of concrete plans is calculated at the age of 28 days. The rate of increase in the age of concrete is highly dependent on the use of cement because cement tends to directly improve its pressing performance. Compressive strength can be calculated by equation 2.1.

$$fc' = \frac{P}{A} \tag{2.1}$$

Description:

fc' = Compressive Strength of Concrete (MPa)
P = Maximum load (N)
A = Cross-sectional area of the test piece (mm^2)

2.2 Strong Adhesion of Reinforced Concrete

In general, the use of steel reinforcement in reinforced concrete structures is to replace the ability to receive tensile force on weak concrete materials. The tensile force that occurs in the concrete structure will then be channeled to the steel reinforcement through an adhesion mechanism (bond), so that the two materials, namely concrete and steel reinforcement, can work together into a single composite material (Ngudiyono et al., 2022). The adhesion mechanism between concrete and reinforcing steel will form a composite action in bearing the load. The adhesion between concrete and rebar steel is influenced by several factors, one of which is the compressive strength of concrete. The adhesion between concrete and threaded reinforcing steel is formed by adhesion, friction, and mechanical interlocking. Mechanical interlocking makes a great contribution to forming an adhesion between concrete and steel. Based on this mechanism, the transfer of force from rebar steel to concrete occurs through the stranding of reinforcing steel (Purwanto et al., 2023).

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$$u = \frac{Pmax}{\pi . d . l} \tag{2.2}$$

Description :
u = Adhesion strength of reinforcement (MPa)
d = Rebar diameter (mm)
Pmax = Maximum tensile load (N)
L = Length of embedded reinforcement (mm)

2.3 Effect of Corrosion on Reinforced Concrete

Corrosion is the process of oxidation of a metal with air or other electrolytes, where air or electrolyte will undergo reduction, so the corrosion process is an electrochemical process. Corrosion occurs through redox reactions, where metals undergo oxidation, while oxygen undergoes reduction. Rust on iron is a brown-red substance (Ariyanto, 2022). Factors that can accelerate the occurrence of corrosion are water and electrolytes (acids or salts). If the reinforcing steel is left in the open for a long time, the reinforcing steel will be in direct contact with rainwater and will accelerate the corrosion process.

One of the main problems in construction work is corrosion in reinforcing steel. Many construction projects continue to use rebar even though they have been corroded. Corrosion on reinforcing steel will cause a decrease in the cross-sectional area so that the adhesion strength between rebar and concrete will be reduced so that the reinforced concrete structure will experience a decrease in structural strength and concrete will peel off and even collapse.

2. RESEARCH METHODS

The research method in this study is an experiment conducted at the Engineering Laboratory of the University of Muhammadiyah West Sumatra.

3.1 Sample Preparation

There are 2 types of reinforcing steel used, namely deformed D19 non-corroded bar purchased at the nearest building store, deformed D19 bar that has corroded, and sampling at the construction project of the Faculty of Veterinary Medicine Campus IV of the University of Muhammadiyah West Sumatra. The length of the rebar steel used is ± 20 cm each placed in the middle of the cube mold with an embedment length of 15 cm.

3.2 Material Preparation

The quality of concrete planned for concrete compressive strength and bond test is K250 concrete quality. Before making a sample, the material to be used is tested first. Material property tests are carried out on fine aggregate materials, coarse aggregates, and cement. In testing material properties, there are several types of tests, namely:

a. Cement
   - Specific gravity of cement
b. Fine aggregate
   - Specific gravity of fine aggregate

- Fine aggregate volume weight
- Fine aggregate fineness modulus
- Test of material passing sieve no.200
- Fine aggregate organic matter examination
- Fine aggregate sludge level inspection
- Fine aggregate moisture content testing
- Specific gravity

c. Coarse aggregate
- Coarse aggregate specific gravity
- Gross aggregate volume weight
- Coarse aggregate fineness modulus
- Examination of coarse aggregate organic substances
- Coarse aggregate sludge content inspection
- Crude aggregate moisture content testing
- Specific gravity

3.3 Mix Design

In general, the volume contained in concrete is ± 68% aggregate, ± 11% cement, ± 17% water, and ± 4% air. Because of the cement hydration process that occurs, water and cement can attach aggregate granules until a solid mass such as stone is formed (Safitri, 2021).

3.4 Sample Testing

After obtaining the results of the mix design, the data from the mix design is used as a benchmark to make a concrete mixture which is then carried out a slump test with the provision of reducing the concrete mix ± 10 cm. After getting the results of concrete mixing according to the plan, fresh concrete is molded into a cube-shaped mold with a size of 15x15x15 cm. The molded concrete is removed from the mold after reaching a 24-hour lifespan. Furthermore, the concrete is cured by soaking the concrete in a water bath for 25 days and is removed for air drying for 3 days.

Concrete compressive strength testing is carried out according to SNI 1974:2011 procedures using the Compression Testing Machine (CTM) compressive strength testing equipment. Concrete that is 28 days old is tested by applying a maximum load characterized by cracks or collapse in the test piece.

The bond test specimen is in the form of a cube with a size of 15x15x15 cm and reinforcing steel is embedded into concrete as deep as the height of the mold, which is 15 cm with the quality of the concrete plan K250. Bond test testing is also carried out using a Compression Testing Machine (CTM) by way test pieces that have reached the age of 28 days are inserted into the CTM device. On the surface of the base of the test piece, a base that has been perforated in the center with a hole diameter of ± 23 mm and a depth of 5 cm. The empty cavity created by the perforated base allows the reinforcement to slide into it without any hindrance when it is forced or axially pressed from above. The concrete sample is then pressed with a maximum load until the test specimen undergoes adhesion collapse (bond stress failure) so that the magnitude of the compressive force will be obtained. The results of these tests are then analyzed and used to make data-driven decisions.

4. RESULTS AND DISCUSSION

4.1 Mechanical Properties of Concrete

In this research, the materials used are coarse aggregate derived from Palembayan crushed stone, fine aggregate from Palembayan tidal sand, and Portland Composite Cement (PCC) type of Padang cement. The results of the material test are presented in Table 1.

Table 1. Mechanical Properties of Concrete K250

Material	Testing	Result
Cement	Specific Gravity	2,83
Fine Aggregate	Specific Gravity	2,51
	Aggregate Volume Weight	1,37
	Fine modulus of granules	3,26
	Ingredients Passed Sieve No.200	3,08
	Sludge Content	4,95
	Absorption (%)	3,31
Coarse Aggregate	Berat Jenis	2,19
	Aggregate Volume Weight	1,61
	Fine modulus of granules	4,55
	Moisture Content	1,24
	Absorption (%)	2,96

Source: Personal data, 2024

4.2 Mix Design

In this study, the mix design was carried out by SNI 03-2834-2000 (Procedures for Making Normal Concrete Mixed Plans) with the quality of the K250 or fc' plan concrete 20.75 MPa. The mix design for 1 test piece is obtained from the results of testing the concrete-forming properties described in Table 2.

Table 2. Mix Design Concrete K250

Cement	1,263	Kg
Water	0,682	Kg
Coarse Aggregate	1,857	Kg
Fine Aggregate	3,151	kg

Source: Personal data, 2024

4.3 Concrete Compressive Strength Testing

Compressive strength testing is carried out using a CTM (compression testing machine) tool. The compressive strength test was carried out after the concrete reached the age of 28 days and had been cured for 25 days by soaking the concrete in a water bath and removing it for air drying for 3 days.

Table 3. Results of Concrete Compressive Strength Test K250

Test Specimen	Weight (kg)	Area mm2 (A)	Load (KN)	Load (N)	Compressive Strength (Mpa)	Kg/cm2	SD	∑	fc' (Mpa)
a	b	c	d	e = (d) x 1000	f = (d) / (c) x 10	g = (g) x 0.83 x 10	h	i = (g) + (h)	j = (i) x 0.083
1	7,082	225000	430	430000	19,11	230,25	9,117	239,37	19,86785
2	7,113	225000	435	435000	19,33	232,93	9,117	242,05	20,09007
3	7,540	225000	460	460000	20,44	246,32	9,117	255,44	21,20118
4	7,467	225000	470	470000	20,89	251,67	9,117	260,79	21,64562
5	7,582	225000	465	465000	20,67	249,00	9,117	258,11	21,4234
Average compressive strength = 20,85 MPa									

Source: Personal data, 2024

Based on Table 3, the compressive strength applied to 5 samples produced an average compressive strength of fc' 20.85 MPa. The result meets the quality of the planned concrete, which is fc' 20.75 MPa.

4.4 Bond Test

Based on ASTM C.234 – 1980 (Standard Test Method for Comparing Concretes based on the Bond Developed with Reinforcing Steel) bond test is carried out to calculate the amount of shear force between reinforcement and concrete through a compression test. Threaded reinforcing steel is designed to be strong in concrete adhesion and high rebar, reinforcing steel is used to withstand the compressive force of concrete along with tensile reinforcing steel.

To calculate the adhesion strength between concrete and reinforcement or the shear force against the reinforcement can be calculated by equation 4.1.

$$\tau = \frac{Pmax}{\pi\ D\ t} \qquad (4.1)$$

Description:
P max = Maximum press load (KN)
D = Diameter of reinforcing steel (mm)
t = Height of reinforced steel covered in concrete (mm)
π = 22/7

Table 4. Testing of Corroded Deformed Bar D19 Adhesion Strength

Concrete Age		**28 days**		
Sample		**I**	**II**	**III**
Maximum Compressive Strength	KN	5	7	4
Reinforcement Diameter	mm	19	19	19
Length of Reinforcement Covered in Concrete	mm	150	150	150
Strong Adhesion	N/mm^2	0,56	0,78	0,45
Average Strong Adhesion	N/mm^2	0,60		

Source: Personal data, 2024

Based on Table 4, the results of the reinforced concrete bond test using D19 deformed bars have very low corrosion, namely 0.60 N/mm2. This is because corrosive substances erode the surface layer of rebar steel and result in a reduction in the bearing capacity of rebar steel in resisting the tensile force and bonding between rebar steel and concrete.

Table 5. Testing of Deformed Bar D19 Non-Corrosion Adhesion Strength

Concrete Age		**28 days**		
Sample		**I**	**II**	**III**
Maximum Compressive Strength	KN	20	15	10
Reinforcement Diameter	mm	19	19	19
Length of Reinforcement Covered in Concrete	mm	150	150	150
Strong Adhesion	N/mm^2	2,24	1,68	1,12
Average Strong Adhesion	N/mm^2	1,68		

Source: Personal data, 2024

Based on Table 5, the results were obtained that the bond test of reinforced concrete using non-corroded D19 deformed bars was higher than that of reinforced concrete using corroded deformed bars, which was 1.68 N/mm2. Based on the comparison of the results of the bond test between corroded D19 deformed bar and non-corrosive D19 deformed bar, it can be concluded that before reinforcing steel is used to make reinforced concrete, it is better to ensure that there are no corroded parts by cleaning the corroded reinforcing steel surface.

CONCLUSION

The conclusions obtained from this study are:

1. Corrosion is an electrochemical process in which an oxidation process occurs in a metal with air or other electrolytes.
2. Corrosion in rebar steel can cause the diameter of the rebar cross-section to decrease because the corrosive substance erodes the rebar layer. Because of this, the carrying capacity of reinforced concrete is reduced in bearing the load.
3. Many construction projects have stopped and reinforcing steel is left in the open so that it causes corrosion, it is better that before the construction work is carried out, the corrosion on the rebar steel should be cleaned first by one of the ways is scraping.
4. Corroded reinforcing steel has lower adhesion strength to concrete than non-corroded reinforcing steel.
5. The failure of the test piece is strong adhesion occurs due to the cracking of the concrete until the rebar comes out.

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