Effects of Anchoring Depth on the Bonding Strength of Steel in High Quality Reinforcement Concrete

Suparjo[1], Iza Syiriana Azizah[1], Yuli Panca Asmara[2]

-[1]Engineering Faculty, University of Mataram, West Nusa Tenggara, Indonesia
[2]INTI International Universiti, Faculty of Engineering and Quantity Surveying, Nilai 71800 Negeri Sembilan, Malaysia

Correspondence: suparjo14867@yahoo.com

Abstract. One of the key objectives of using steel reinforcement in concrete is to enhance its tensile strength. To achieve the desired strength, it is crucial to consider the depth of anchorage. The adhesion strength between the reinforcing steel and concrete is effective when the reinforcement bars are securely embedded in the concrete at a specific depth. This study focused on investigating the impact of anchoring depth on the adhesive strength of steel reinforcement in the high quality concrete. Various tests including shear stress, tensile strength, bonding strength and deformation were conducted on the concrete with several depth of steel anchorage. Steel reinforcement with a diameter of 10 mm and a steel yield stress (f_y) of 328 MPa was utilized in cylindrical concretes with anchorage depths ranging from 50 mm to 250 mm. The bonding strength was evaluated using the pull-out test method. The test results showed that the higher the compressive strength of concrete, the lower the percentage of shear strength to compressive strength produced for each type of concrete. In high strength concrete, the maximum bonding strength was 6.245 MPa at 150 mm anchorage depth and 3.795 MPa for the minimum bonding strength at 250 mm anchorage depth. The bond distribution length was observed to exceed the shear strength distribution length, highlighting the occurrence of bonding failure in all specimens at the point where the steel reinforcement was affixed to the concrete.

Keyword*: Plain Reinforcement, Anchoring Depth, Bond Strength, High Strength*

1. Introduction

Concrete is a composite material comprised of Portland cement, water, and aggregate, mixed in specific ratios. When the mixture is poured into a mold and allowed to set, it undergoes a process called hydration, gradually hardening into a solid mass. This hardening occurs due to a chemical reaction between water and cement, which continues over an extended period of time, resulting in increased strength as the concrete ages[1-10]. The composition of concrete consists of various components, including air, Portland cement, and aggregate, each serving a distinct purpose. The hardened concrete can be likened to artificial stone, with voids between larger grains (coarse aggregate such as gravel or crushed stone) filled by smaller grains (fine aggregate such as sand), while the spaces between the fine aggregate grains are filled by cement paste and air. The cement paste not only fills the voids between the fine aggregates but also acts as an adhesive or binder during the hardening process, ensuring strong adhesion between the aggregate particles, resulting in a compact and dense mass [11-20].

The design and analysis of reinforced concrete structures typically are assumed to have perfect of bonding strength between steel and concrete. The bonding strength between steel reinforcement and concrete is crucial and should be embedded firmly at a certain depth. Brian Tumiwa (2016)[27} conducted research on the bond stress between steel and concrete with a compressive strength of 40 MPa. Cylindrical specimens were used in the study, which revealed bond stress failures, characterized by transverse cracks and longitudinal cracks in the concrete. The bond stress value obtained was 15.3 MPa for the concrete with a compressive strength of 40 MPa. For reinforced concrete to function effectively as a composite material, where the reinforcing steel bars work in synergy with the concrete, it is crucial to achieve good force transfer between the materials. This necessitates a strong bond between the concrete and the reinforcement, along with an adequate thickness of concrete cover. Reinforcing steel can transmit force efficiently through the steel bond within the concrete up to a certain depth, known as the development length (Vis. 1993)[29]. Typically, the bond strength test of reinforcing steel exhibited a decrease in bond strength with the addition of recycled coarse aggregate at proportions of 20%, 40%, 60%, 80%, and 100%. For plain reinforcing steel, the decrease was 4.946%, 9.115%, 10.004%, 11.857%, and 14.724%, respectively. In the case of deformed reinforcing steel, the decrease was 4.018%, 7.402%, 8.635%, 8.866%, and 8.931% when compared to concrete using crushed stone aggregate (L. Agil Hidayat P., 2017)[17].

Pull-out experiments can provide valuable insights into the bonding efficiency of different types of reinforcement surfaces and the embedment length. However, these experiments do not directly provide the actual bond stress values for structural frames. In such experiments, both the surrounding concrete and steel experience the same tension (Nawy, 1990)[20].

2. Experimental Setup

The materials used in this study were

a) Portland cement type 1

The cement used as a binder for the concrete mix was Portland cement type 1 with the brand Tiga Roda in a pack of 50 kg. Visual observation of tightly closed packaging, fine grained materials and no clumping.

b) Fine aggregate (Sand)

The fine aggregate used in this study was river sand which was readily available at the Structures and Materials Laboratory, Faculty of Engineering, University of Mataram.

c) Coarse aggregate

The normal aggregate used in this study was coarse crushed stone aggregate. The normal aggregate of crushed stone used was aggregate that was already available at the Structure and Materials Laboratory, Faculty of Engineering, University of Mataram. The crushed stone diameter used was crushed stone with a maximum diameter of 20 mm. In this study, plain reinforcing steel with a diameter of 10 mm was used with a yield stress (*fy)* of 328 MPa.

d) Preparation of test speciment

Concrete Mix Design (Mix Design)

Concrete mix planning was intended to determine the composition or proportions of the concrete constituents. The proportions of these concrete constituents were determined through a concrete mix design. This was done so that the proportion of the mixture can meet the technical requirements economically. High quality concrete mix design was planned based on SNI 7656-2012, Mix Selection Procedures for Normal Concrete, Heavy Concrete and Mass Concrete [4].

e) Testing methodology

The shear strength test of the concrete was carried out using a compression testing machine after the specimen was 28 days old with the size of the specimen being 30 x 20 x 7.5 cm. Steel tensile strength testing for concrete reinforcement was carried out to determine the stress of the steel at the time of yielding and maximum conditions. This test was carried out using the UTM (Universal Testing Machine) tool. The concrete compressive strength test was conducted to obtain the maximum load that can be supported by a concrete cylinder.

3. Results and Discussion

From the results of material inspection at the Laboratory, concrete materials such as sand, crushed stone and pumice meet the requirements as concrete constituents.

3.1 Steel tensile strength testing

The results of the tensile strength test of steel can be seen in the Table 1.

Table 1. Yield stress and maximum stress of reinforcing steel bar used for reinforcement concrete.

no	Diameter	P (N)	Yield stress (N/mm^2)	P (N)	Maximum stress (N/mm^2)
1	9.87	20570	298	28480	427
2	9.84	20330	296	29200	424
3	9.83	26840	392	39020	569
Average			328		473

3.2 Compressive Strength Testing

The test results for the adhesive strength of high quality concrete was 61.657 Mpa with a design compressive strength of 50 Mpa. From these results the compressive strength obtained was greater than the design compressive strength.

3.3 Elastic Modulus Testing

Testing the modulus of elasticity of concrete was carried out simultaneously with testing the compressive strength of concrete using a dial gauge. The results were recorded in this test by reading how much the work load was and how much the decrease has occurred in the test object causing the test object to break or collapse. The elastic modulus values obtained in this study was 40093.123 MPa for high strength concrete. The results show that the higher the quality of the concrete, the greater the elastic modulus value.

3.4 Shear Strength Testing

The shear strength test of the concrete was carried out using a Compression Testing Machine after the specimen was 28 days old with the size of the specimen being 30 x 20 x 7.5 cm. The shear strength obtained in high strength concrete was 13.555 Mpa.

4. Pull out test

4.1 Bonding strength test

The test results for the bond strength of high quality concrete at all variations in anchorage depth is presented at Figure 1.

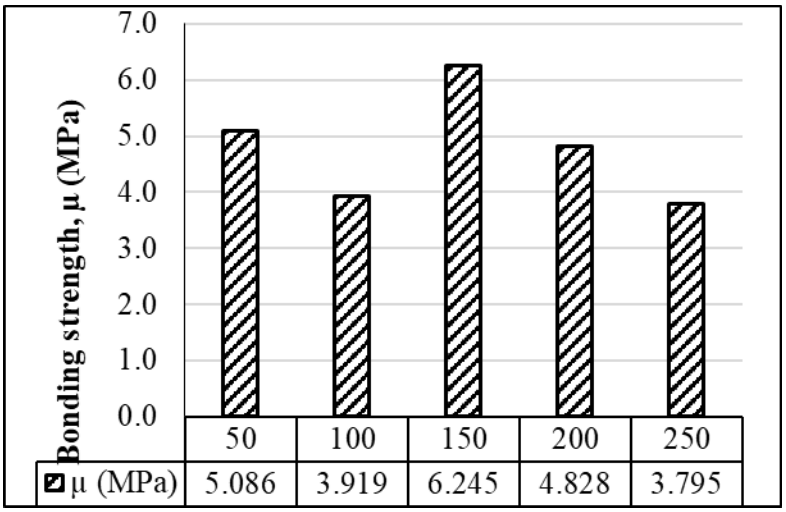

Figure 1. Bonding strength between steel and concrete in high quality concrete.

From the test results, it was found that the bond strength value from anchorage depth of 50 mm to 100 mm decreased, while from anchorage depth of 100 mm to 150 mm experienced a significant increase. For a depth of 150 mm to 250 mm the bond strength value obtained has decreased. This was because at shallow anchorage depths the steel reinforcement was suspected to have not yet become plastic, whereas at deep anchorage depths the concrete was suspected to have experienced plastic. The steel reinforcement becomes plastic with increasing depth of anchorage which did not significantly affect the ability of the load to withstand the tensile force due to plastic, furthermore the bonding stress will decrease due to the steel experiencing plastic the diameter of the reinforcement decreases so that it loses attachment on the part of the steel that was experiencing plastic zone.

Figure 2 is relationship between load-deformation in high strength concrete can be seen in Figure 8.

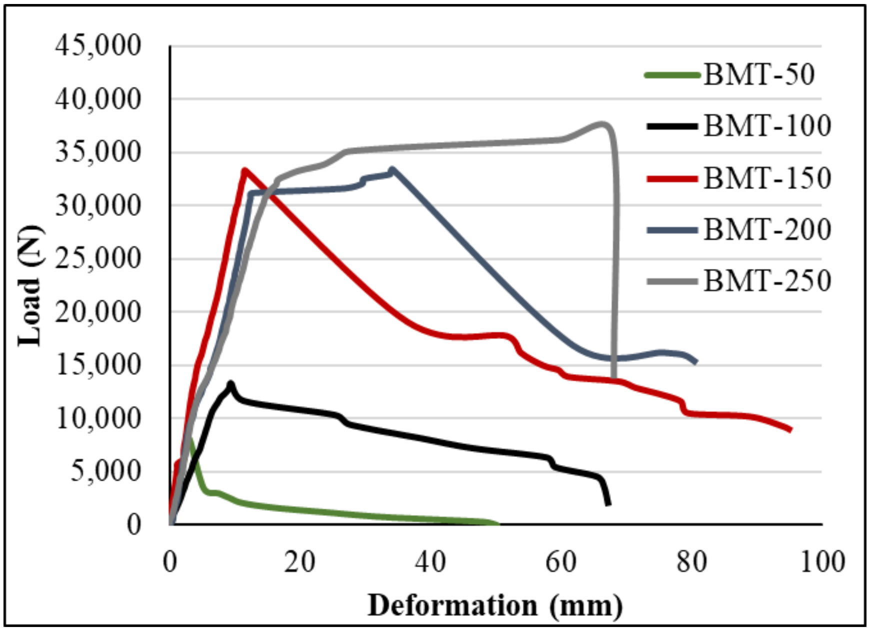

Figure 2. Deformation test of various anchoring depth of high quality reinforcement concrete (BMT).

Figure 2 presents the maximum load achieved at different anchorage depths, highlighting variations in the yield steel stress. At anchorage depths of 50 mm and 100 mm, there was no significant difference observed in the maximum load and deformation values. However, a substantial difference in load and deformation values was observed between the depths of 100 mm and 150 mm, indicating notable changes in behavior. From anchorage depths of 150 mm to 250 mm, the maximum load showed minimal variation. It was possible that at anchorage depths of 200 mm and 250 mm, the diameter of the steel reinforcement reduced or the reinforcement experienced plastic deformation, resulting in detachment of the steel reinforcement from the plastic zone.

4.2 Bonding strength

The results of the calculation of the bonding coefficient values in high quality concrete can be seen in Table 2.

Tabel 2. Coefficient bond of high quality concrete.

Length of anchorage (mm)	μ (bonding strength) (MPa)	db (diameter steel) (mm)	fy (yield stress) (MPa)	Coefficient bond	
				SNI	Exp
50	5,086	9,87	328	0,125	0,079
100	3,919			0,125	0,121
150	6,245			0,125	0,289
200	4,828			0,125	0,298
250	3,795			0,125	0,293

Table 2 shows that at a depth of 50 and 100 mm the value of the bond strength coefficient were not meet criteria for bonding strength. It indicated that the attachment at a depth of 50 and 100 mm did not take place perfectly because the value of the attachment coefficient obtained were smaller than calculation which was equal to 0.125. For depths of 150, 200, and 250 mm it can be stated that the bond strength was perfect because the bond coefficient value was greater than the standard 0.125.

4.3 Safety factor of anchorage

From the table of the relationship between the depth of anchorage and the coefficient of length, it can be graphed the relationship between the safety factor and the depth of anchorage for high strength concrete as can be seen in Figure 3.

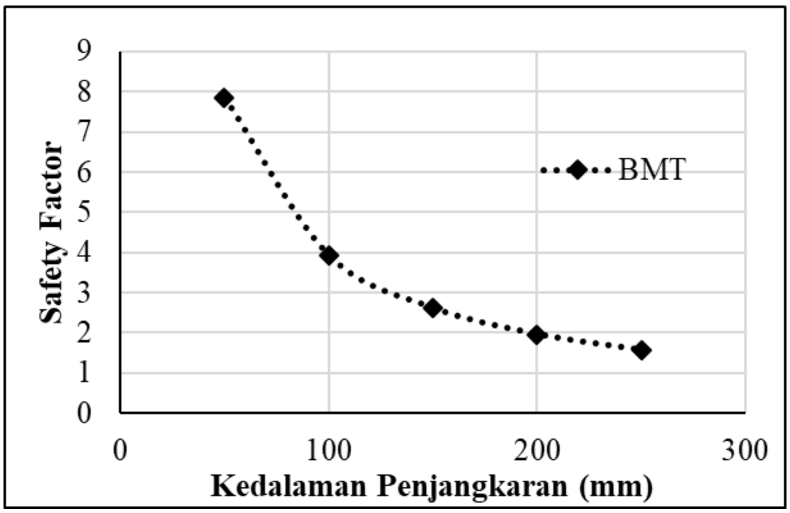

Figure 3. Relationship between safety factor value and depth of anchorage of high quality concrete (BMT).

In high quality concrete the minimum safety factor value was obtained at anchorage depths of 200 and 250 mm. These results indicated that the safety factor value obtained from the experimental results was smaller than the safety factor value specified in SNI 03-2847-2013. This indicated that if the distribution length equation in SNI 03-2847-2013 was applied, the structure was safe for high strength concrete. This study showed that the lower the anchorage depth, the higher the safety factor value obtained.

Conclusion

Based on the test results, data analysis and discussion it can be concluded that:

1. The relationship between compressive strength and shear strength obtained by the percentage of shear strength to compressive strength in high quality concrete was 21.707%,
2. The bond strength obtained at anchorage depths of 50 mm, 100 mm, 150 mm, 200 mm, and 250 mm were 5.086 MPa, 3.919 MPa, 6.245 MPa, 4.828 MPa and 3.795 MPa respectively.

3. The relationship between shear strength and depth of anchorage shows that the bond distribution length was greater than the shear strength distribution length at the same tensile load.
4. Based on the depth of anchorage, the experimental results show that the safety factor value was smaller than the safety factor value given in the SNI 03-2847-2013 equation.

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