Effects of Confinement of Tubular Pipe to Bond Stress between Deformed Steel Bar and Grout

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Keywords: bond stress; steel bar; grout.

Abstract. Grout splice sleeve connector is one of the precast concrete connections that can be used in the precast concrete construction. Under tensile condition, the desired failure mode of a good design of grouted splice sleeve connections is the bar fracture, where the anchorage strength is greater than the yield strength of the connected reinforcing bars. Designer can determine the minimum anchorage length of steel rebar used in the connector if the value of bond stress is known. In this study, the laboratory test was conducted to determine the maximum value of bond stress between the reinforcement bar and grout in the steel pipe to be adopted in connection design. The relationships between bond stress and slip in the splice sleeve connector, the effects of sleeve diameter, sleeve thickness, rebar embedded length and rebar diameter on the bond stress between the reinforcement bar and grout were investigated. A total of twelve grouted splice specimens divided into 2 series with Y12 reinforcement steel bars were experimentally tested under pull-out test. The maximum value of bond stress for D39 and D32 series were 25.2 N/mm2 and 25.09 N/mm2 respectively. The experimental results show that the decrease in diameter of steel pipe show an increase in the ultimate bond strength. Furthermore, the ultimate bond strength of reinforcement bar in grouted splice sleeve is higher when thicker sleeves are adopted. The specimen with shorter embedded length has greater bond strength and the use of larger diameter of steel reinforcement bar in grout splice sleeve shows an increase in the ultimate bond stress between the steel bar and surrounding grout.

Introduction

Precast building systems or IBS systems (Industrialized Building Systems) have become more popular in the construction industry. Meanwhile, cast in-situ method normally faces a lot of problems with low quality and productivity due to insufficient construction time, lack of skills, poor materials used, budget and others. However, one of the methods will can overcome these types of problems is precast building system. Precast concrete structure is a system where parts, members and elements of the structure like beams, slabs, columns and walls will be produced from a factory, delivered to specified site and connect these element together on site to form a building structure. Connection of the precast concrete structure is one of the important parts in the precast system. The connections must have adequate strength to transfer the forces without failure. There are several connection methods used in the precast system available such as welding, bolting, grout splice sleeve and others. The most popular connection method used in the precast system is grout splice sleeve.

Problem Statement

Grouted sleeve connection is important for the stability of the precast structure system in construction. This connection also relies on the bond strength between steel bar and grout. Hence, we must known the value of bond stress in the connector to avoid the splitting failure and bar pull-out due to the uncertain of bond stress value. This value of bond stress is required in the design process, so that the designer can use it to design the minimum anchorage length of reinforcement bar. The appropriate embedded length of steel bar can provided adequate bond stress in the connector and decrease the construction cost.

Objective of Study

There are basically three objectives of this study:

1. To determine the maximum value of bond stress between reinforcement bar and grout in the steel pipe to be adopted in design connection.
2. To obtain the relationship between bond stress and slip in the grout splice sleeve connector.
3. To identify the effect of sleeve diameter, sleeve thickness, rebar embedded length and rebar diameter on the bond stress between reinforcement bar and grout.

Scope of Work

This study was focussed on laboratory testing on tensile pull-out test of the proposed precast concrete connection which comprises of twelve specimens with varying parameters of diameter of sleeve, thickness of sleeve, embedded length and diameter of reinforced bar and all specimens were tested under incremental tensile until failure.

Previous Studies

Previous studies have been conducted on study the effect of different diameter of sleeve found that the diameter of sleeve will be affect the bond strength. According to the research by Juliyanah Sama'an, [1] the pull-out specimen with the smaller diameter of sleeve has greater bond strength between reinforced bar and grout. In addition, based on the research done by A.Alias, [2] they concluded that the bond strength increases as the small reduction in sleeve diameter. This result could be due to the increase of confining pressure, as the different of external and internal diameter of the sleeve connector. The sleeve generates normal pressure on the grout as the sleeve stretches during loading, thus increasing the grip between the grout and the reinforcement bar. Besides that, the internal sleeve blocked the motion of the grout, thus resulting in a high compressive stress at the interface of the sleeve, particularly between the internal sleeve and grout (see Figure 1). This load transfer mechanism effectively engages the confinement action generated by the reduction in sleeve size, thus resulting in a strong bonding mechanism between the spliced reinforcement bars and the grout [3].

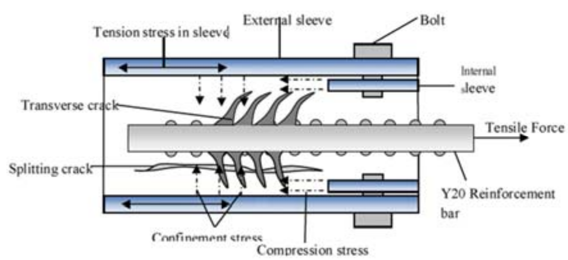

Figure 1: Load transfer mechanism in grouted sleeve connector.

Based on the research carried out by Ali A.Sayadi,[8] the increasing the thickness of sleeve led to an increase in radial strength, sleeve stiffness, and confinement pressure, which prevented the propagation of radial cracks and expansion of grout. Amin Eina et al. [4] studied the grout-filled pipe splices for precast concrete construction. This study found that the embedded length of reinforced steel bar with seven times of diameter bar can achieve high strength depends on compressive strength of grout and sleeve provided. In addition, the bond strength can be improved with the use of shear key on the inside of both ends of the pipe. In contrast, the research was conducted by Ismaeel H.Musa [5], he stated that the specimen with smaller embedded length has greater bond strength than that of the specimens with the large embedded length.

Previous research based on study the effect of different diameter bar, the research were conducted by Hadi, M. N. [6] and Ismaeel H.Musa [5], it stated that the pull-out specimens with the smaller bar size has greater bond strength than that of specimens with the large bar diameter. Based on the research done by Soroushian and Choi [7], investigated the local bond stress behavior of deformed bars in confined concrete. They concluded that the bond strength decreased linearly as the bar diameter increased.

Methodology

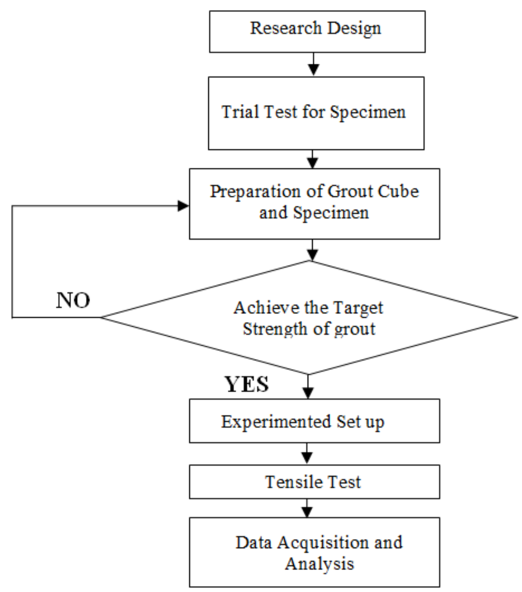

Figure 2: Flow Chart of Methodology

Material

Materials used in this research include grout, high yield steel bar, SGP galvanised iron pipe, bolt and nut. In this study, the grout used was Fosroc® Conbextra GP grout which was designed to have compressive strength of 40N/mm2 at the age of 7th day and compressive strength of 60N/mm2 at 28th day. The high yield steel bars Y12 were used as reinforcement bar in the specimens. The steel pipe with 2mm, 3.2mm and 4.0mm thickness and 300mm length were made of galvanised iron cylinder with plain surface inside the steel pipe were used as sleeve and 25mm length as shear keys.

Specimens Preparation

A total of twelve specimens were divided into to 2 series namely D32 and D39 series. Each grouted sleeve connector consisted of a galvanised iron pipe with 300mm length. The 248 mm and 320 mm length of high yield steel bar was placed at the center of the steel pipe. Steel pipe of 25 mm length were bolted onto the inner surface of pipe as the shear keys at both ends of the steel sleeve. This will provide interlocking mechanisms to enhance the bond property between the grout and the sleeve, thus preventing the grout from slipping. Figure 3 shows the component of a Splice Sleeve. Table 1 shows the properties of the specimens.

A wooden frame was prepared to hold the specimens in position before non shrinking grout was poured into the sleeve. The steel bars were inserted into the sleeves from both ends, encountering each other at required embedded length before they were tied onto the wooden frames. All specimens were arranged in vertical position, while the steel bars were aligned along the central axis of the sleeve. Then, grout was poured into the sleeve to fill the spaces within the sleeve. All specimens were tested under incremental tensile until failure. Figure 4 shows the arrangement of all specimens in vertical position.

Before the tensile pull-out test was conducted, the cube compression test was tested to obtain the compressive strength of grout. A total of six cubes specimen with dimensions 70mm x 70mm x 70mm were prepared using the steel moulds as shows as Figure 5. After 24 hours these moulds were removed and test specimens were put in water for curing.

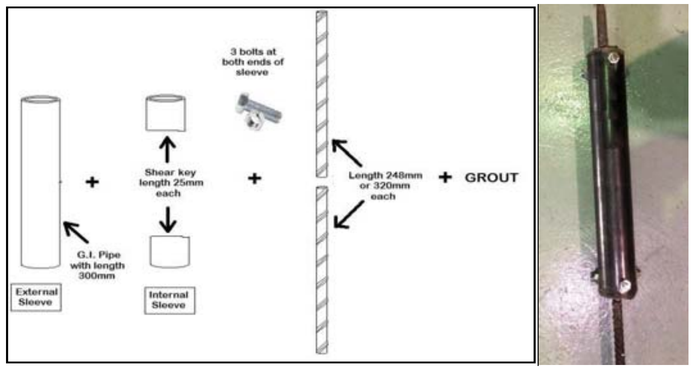

Figure 3: The Component of a Splice Sleeve Specimen

Table 1: Properties of the Specimen

Series	Sample	External Diameter of Sleeve, D_e (mm)	Inner Diameter of Sleeve, D_i (mm)	Thickness of Steel Pipe, t (mm)	Embedded Length, L_e (mm)	
D39	D39T2L48	39	32	2.0	48	4d
	D39T2L120	39	32	2.0	120	10d
	D39T3.2L48	39	32	3.2	48	4d
	D39T3.2L120	39	32	3.2	120	10d
	D39T4L48	39	32	4.0	48	4d
	D39T4L120	39	32	4.0	120	10d
D32	D32T2L48	32	25	2.0	48	4d
	D32T2L120	32	25	2.0	120	10d
	D32T3.2L48	32	25	3.2	48	4d
	D32T3.2L120	32	25	3.2	120	10d
	D32T4L48	32	25	4.0	48	4d
	D324L120	32	25	4.0	120	10d

Figure 4: Arrangement of All Specimens in Vertical Position

Figure 5: Steel Mould Size 70x70x70mm

Result and Discussion

Compression Test for Grout

The compressive strength of grout must exceed 60 N/mm2 before the tensile pull-out test can be carried out. The required compressive strength of the Fosroc® Conbextra GP grout at age of 7th day is 40 N/mm2. In this study, six of cube samples were prepared which two of the samples were tested at age of 5th day, another two samples at age of 7th day, and the rest were tested during the tensile pull-out test was conducted. The result is shown in Table 2. Since the average value of the grout strength was 54.90 N/mm2 at age of 7th, all cubes had achieved satisfactory grout strength which were higher than the target strength of 40 N/mm2. Furthermore, on the day during the tensile pull-out test was conducted, the average value of grout strength was 60.12 N/mm2 where the compressive strength of the grout had reached the target strength of 60 N/mm2.

Table 2: Result of Cube Test for Fosroc® Conbextra GP grout

Age of Sample	Sample	Ultimate Loading (kN)	Ultimate Stress (N/mm^2)	Average (N/mm^2)
5th day	A1	242.11	49.41	47.68
	A2	241.98	45.95	
7th day	B1	272.12	55.53	54.90
	B2	270.35	54.26	
During Tensile Test was Conducted	C1	285.68	58.30	60.12
	C2	303.48	61.93	

Tensile Test of Reinforcement Steel bar Y12

Table 3 shows the result of tensile test for Y12 steel bar with 650mm length as a control specimen tested under incremental tensile load. This test was conducted to obtain the relationship between tensile load against displacement for Y12 steel bar as shown as Figure 6. The result shows that the maximum ultimate tensile load was 70.4 kN with 44.2 mm displacement.

Table 3: Result for Tensile Pull-out Test for Y12 Steel bar

Sample	Tensile Load, P (kN)	Displacement, ΔL (mm)
Y12	70.4	44.2

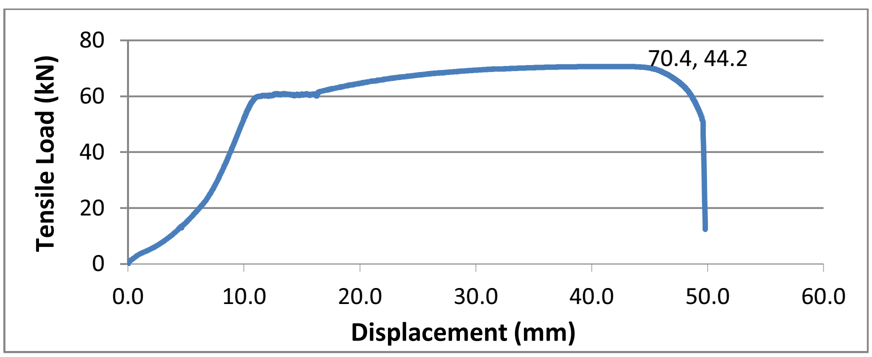

Figure 6: Tensile Load against Displacement for Y12 Reinforcement

Tensile Test for All Specimens

All the specimens were placed vertically on the platform of the DARTEC Universal Tensile Machine, while the two ends of the steel bars were gripped by the actuator of the machine, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, which is plotted against displacement. Table 4 shows the result of tensile pull-out test for all specimens tested under incremental tensile until failed.

Figure 7 and Figure 8 show the graph of tensile load against displacement for D39 and D32. Based on the result collected from the laboratory testing, the high tensile load for D39 is 76.2 kN whereas for D32 is 74.4 kN. Besides that, Figure 9 shows the corresponding three failure modes: ie (a) bar fractured; (b) bar pullout; (c) internal sleeve slipped. Bar fractured occur to specimens D39T2L120, D39T3.2L120, D39T4L120, and D32T2L120. However, bar pullout failure occur to most of specimens D39T2L48, D39T3.2L48, D39T4L48, D32T2L48, D32T3.2L48, D32T4L48 and D32T4L120 whereas the internal sleeve slipped failure mode occur to D32T3.2L120 only.

Table 4: Result for Tensile Pull-out Test for all Specimens

Series	Sample	Tensile Load, P (kN)	Displacement, ΔL (mm)	Bond Strength, τ_B (N/mm^2)	Failure Mode
D39	D39T2L48	36.2	3.27	20.00	Bar pullout
	D39T2L120	76.2	18.98	16.87	Bar fractured
	D39T3.2L48	46.0	4.95	25.20	Bar pullout
	D39T3.2L120	72.9	25.83	16.11	Bar fractured
	D39T4L48	35.0	4.46	19.34	Bar pullout
	D39T4L120	74.2	26.04	16.34	Bar fractured
D32	D32T2L48	43.7	5.19	24.09	Bar pullout
	D32T2L120	74.4	30.95	16.45	Bar fractured
	D32T3.2L48	33.8	6.13	18.68	Bar pullout
	D32T3.2L120	45.2	8.53	9.99	Internal sleeve slipped
	D32T4L48	45.4	6.57	25.09	Bar pullout
	D32T4L120	63.7	5.55	14.08	Bar pullout

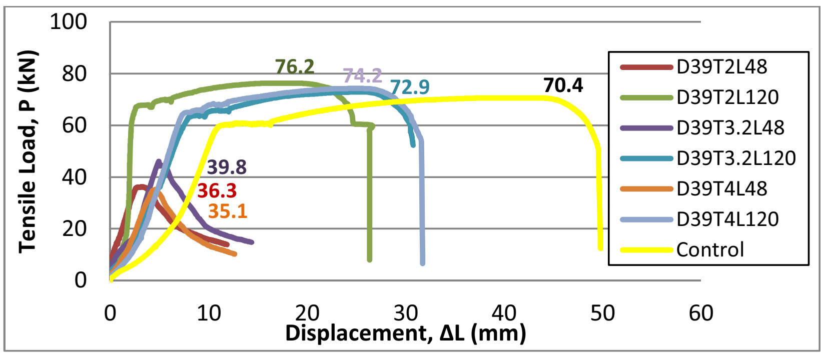

Figure 7: Graph of Tensile Load against Displacement for D39

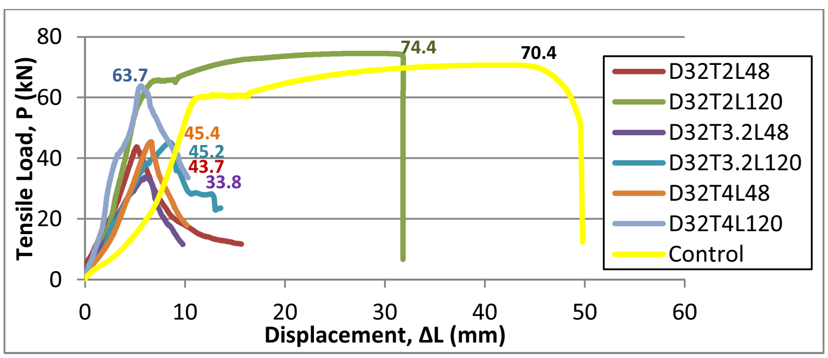

Figure 8: Graph of Tensile Load against Displacement for D32

a) Bar Fractured b) Bar Pullout c) Internal Sleeve Slipped

Figure 9: Failure Modes

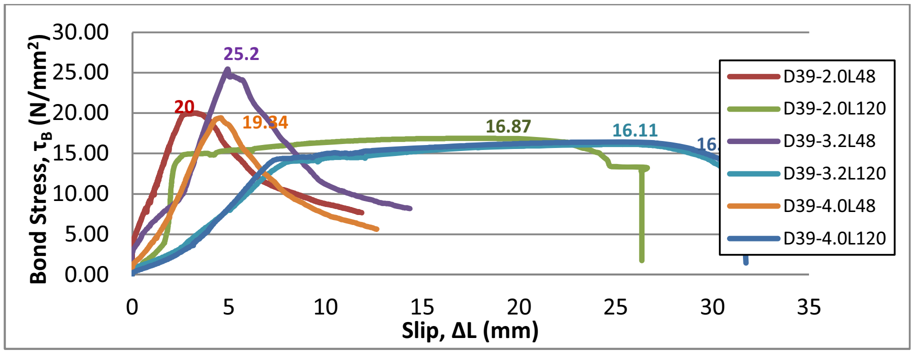

Figure 10: Graph of Bond Stress against Slip for D39

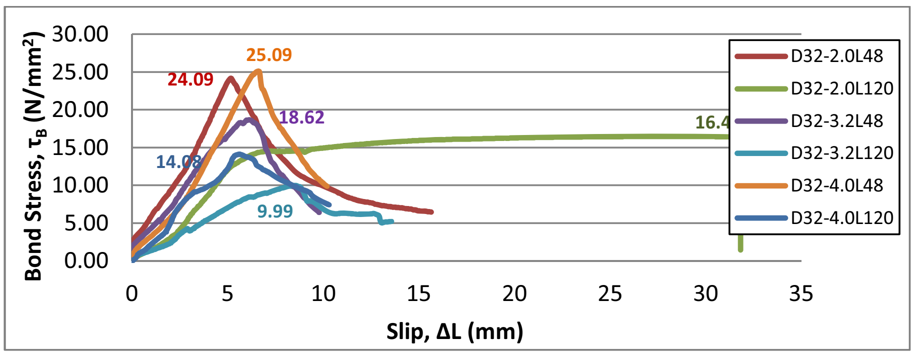

Figure 11: Graph of Bond Stress against Slip for D32

Figure 10 and Figure 11 show the graph of bond stress against slip for D39 and D32. For uniform bond, the bond stress can be expressed as:

$$\tau_B = \frac{P_{max}}{\pi d_b L_e} \quad (1)$$

where Pmax is the maximum pullout load, db is the diameter of the bar and Le is the embedded bar length. From this graph we can see that the grout splice sleeve consist of higher level of stiffness for bond stress before the slip value was approximately 4.95mm. Bond stress become weaker as the slip value exceeded approximately 4.95mm. Therefore, the bond stress is smaller when the embedded length of reinforced bar increase. The safe value of bond strength was 16.0 N/mm2.

Effect of the Parameters

Effect of Different Diameter of Sleeve. Based on Figure 12, we can see that, the sleeve with diameter of 39 mm shows that two specimens, T2L120 and T3.2L48, out of four categories had the highest bond strength of 16.87 N/mm^2 and 25.2 N/mm^2 respectively. Similar to diameter of 32 mm shows that two out of four categories, T2L48 and T4L48 had the highest bond strength of 24.09 N/mm^2 and 25.09 N/mm^2 respectively. However, among the specimens where using the embedded length 4 times the reinforcement bars diameter have two out of three categories have the highest bond strength. Therefore, we can say that the specimens with the smaller diameter of sleeve had larger bond strength between reinforced bar and grout.

The results of tensile pull-out test recorded by Juliyanah Sama'an [1] concluded that the bond strength increases as the sleeve diameter reduces. The study shows that connectors with a smaller diameter of external and internal sleeve perform better. The smaller diameter increases the confinement action and thus increases the bond strength. The internal sleeve essentially blocks the grout movement from being pulled out and provides some confining pressures [2].

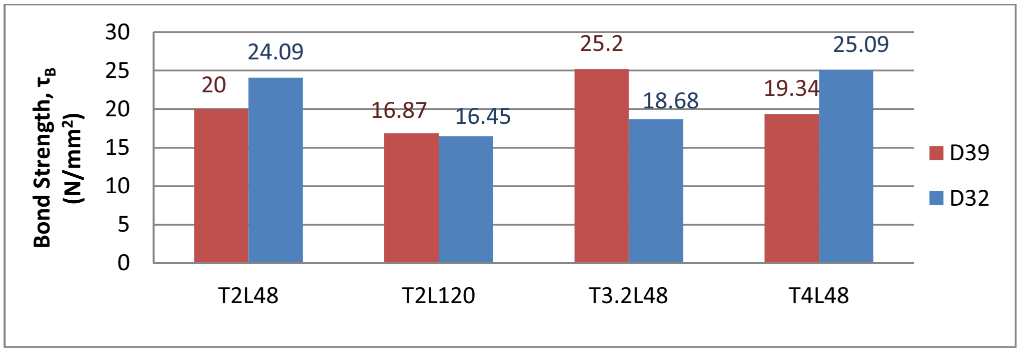

Figure 12: Bond Strength based on All Specimens for Effect of Different Diameter of Sleeve

Effect of Different Thickness of Sleeve. Figure 13 shows the graph of bond strength for all specimens based on effect of different thickness of sleeve which are 2 mm, 3.2 mm and 4 mm. From the graph, we can see that two out of three the highest value of bond strength for T4 are D39L120 and D32L48 whereas for T3.2 is D39L48. Therefore, we can conclude that the larger thickness of sleeve, the greater value of bond strength between grout and reinforced bar.

Based on the research have been done by Ali A.Sayadi [8], it was found that the increasing the thickness of sleeve led to an increase in radial strength, sleeve stiffness, and confinement pressure, which prevented the propagation of radial cracks and expansion of grout. This research proved the larger thickness of sleeve, the higher bond strength that can be reached.

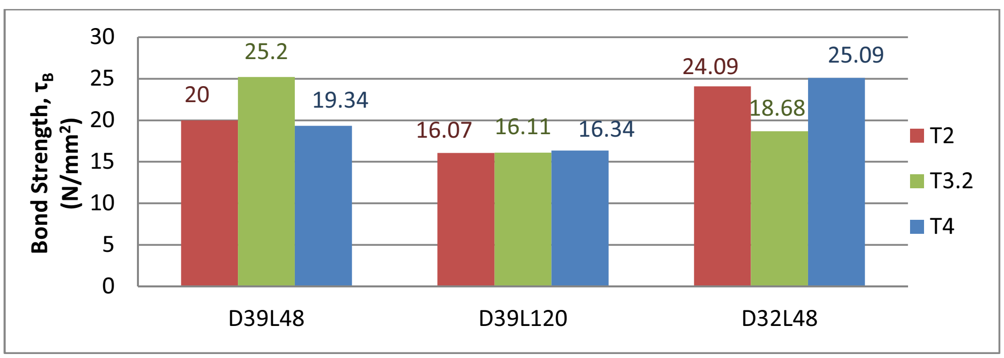

Figure 13: Bond Strength based on All Specimens for Effect of Different Thickness of Sleeve

Effect of Different Embedded Length of Reinforced Bar. From the result recorded as shown as Figure 14, we can see that, the embedded length of 48 mm which is 4 times the Y12 steel bar diameter has the highest the bond strength compared to the embedded length of 120 mm which is 10 times the Y12 steel bar diameter. From other point of view, the specimens L120 with categories D39T2, D39T3.2, D39T4 and D32T2 failed in bar fractured, whereas specimens D32T3.2 and D32T4 failed in bar bond slipped. In this research, the effective embedded length of reinforcement, L_e = embedded length of Y12 steel bar - the length of the shear key steel pipe (25 mm). Hence, 95 mm effective embedded length, approximately 8 times the reinforcement bar diameter had already achieved sufficient bond strength to outstrip tensile capacity of the reinforcement.

Amin Eina et al. [4] studied the grout-filled pipe splices for precast concrete construction. In that studied found that the embedded length of reinforced steel bar with seven times of diameter bar can achieve high strength depends on compressive strength of grout and sleeve provided. In addition, the bond strength can be improved with the use of shear key on the inside of both ends of the pipe. In contrast, the research was conducted by Ismaeel H.Musa [5], he stated that the specimen with smaller embedded length has greater bond strength than that of the specimens with the large embedded length.

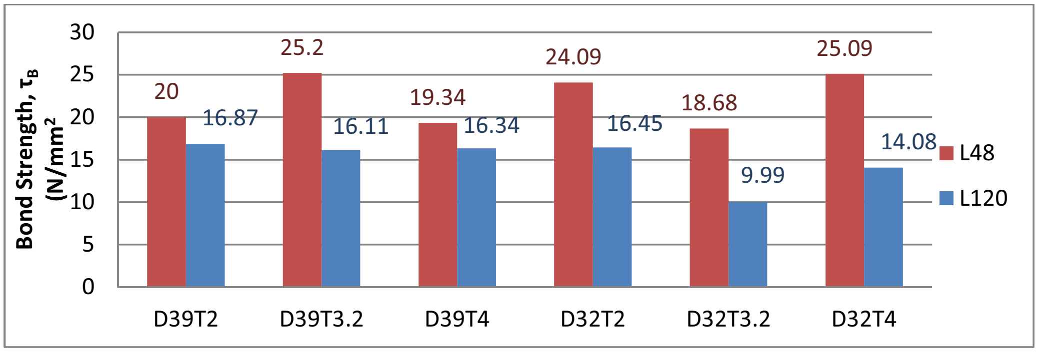

Figure 14: Graph of Bond Strength based on All Specimens for Effect of Different Embedded Length of Reinforced Bar

Effect of Different Diameter Bar. Figure 15 shows the graph of bond strength of all specimens based with different diameters of reinforcement bar. Based on this figure we can see that Y16 bar with sleeve diameter of D39 had two specimens D39T2-4d and D39T4-4d gained the highest bond strength out of three categories. Meanwhile, Y12 steel bar had only one that gained the highest bond strength out of three categories which is D39T3.2-4d. So, we can conclude that the larger diameter of reinforcement bar has greater bond strength.

Soroushian and Choi [7], investigated the local bond stress behavior of deformed bars in confined concrete. They concluded that the bond strength decreased linearly as the bar diameter increased.

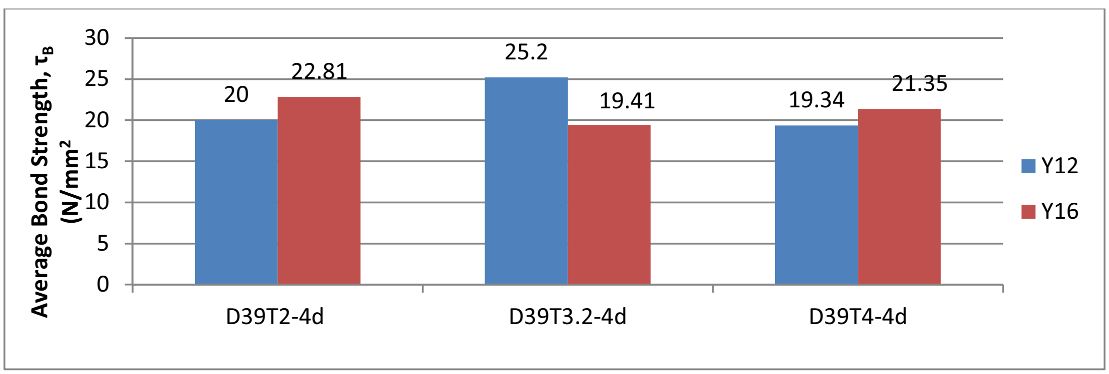

Figure 15: Bond Strength based on All Specimens for Effect of Different Diameter of Reinforced Bar for D39

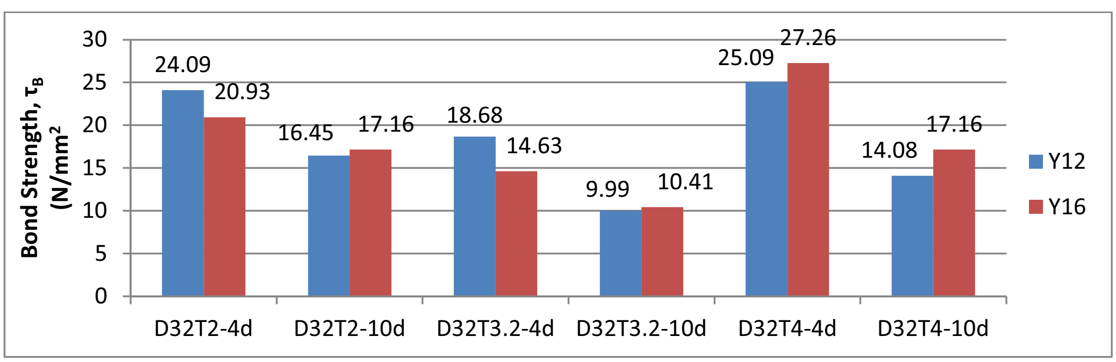

Figure 16: Bond Strength based on All Specimens for Effect of Different Diameter of Reinforced Bar for D32

Based on the graph as shown as Figure 16, Y12 steel bar had two of the highest of bond strength which is D32T2-4d and D32T3.2-4d. Meanwhile, Y16 steel bar had four specimens that gained the highest value of bond strength which are D32T2-10d, D32T3.2-10d, D32T4-4d and D32T4-10d. So that, mostly the highest values of bond strength occurred in the connections with sleeve diameter of D32 and Y16 steel bar.

Previous research based on study the effect of different diameter bar, the research were conducted by Hadi, M. N. [6] and Ismaeel H.Musa [5], it stated that the pull-out specimens with the smaller bar size has greater bond strength than that of specimens with the large bar diameter. Compared to the result from this research, we can conclude that the diameter of reinforced bar will affect the result of tensile test.

Conclusion

Conclusions are made base on the objectives of this study and also from observations done during the entire whole course of this study. This research has shown the effects of confinement of tubular pipe to bond stress between deformed steel bar and grout. The conclusions from this research based on the experimental results are:

Objective 1:

1. The maximum value of bond stress between reinforcement bar and grout for D39 is 25.2 N/mm^2.
2. The maximum value of bond stress between reinforcement bar and grout for D32 is 25.09 N/mm^2.

Objective 2:

1. Grouted splice sleeve for specimen D39 had higher stiffness prior to the slip at approximately 4.95 mm. Bond stress became weaker as the slip value exceeded 4.95 mm.
2. Grouted splice sleeve for specimen D32 had higher stiffness prior to the slip at approximately 6.57 mm. Bond stress became weaker as the slip value exceeded 6.57 mm.

Objective 3:

1. The diameter of steel pipe played a very important role to the bond stress of the grout splice sleeve. The smaller the diameter of steel pipe, the higher the ultimate bond stress. Smaller diameter of sleeve provides better confinement effect to improve the interlocking mechanism between the steel bars and grout of the connector.
2. The ultimate bond stress value of grout splice sleeve is higher with thicker sleeve.
3. The specimen with smaller embedded length has greater bond strength than that of the specimens with the larger embedded length.
4. Short effective embedded length of reinforcement, i.e. 8 times the reinforcement bar diameter had already able to achieve the desired sleeve tensile capacity provided with high grout compressive strength in the splice sleeve.
5. The use of larger diameter of steel reinforcement bar in grout splice sleeve shows an increase in the ultimate bond stress between the steel bar and surrounding grout.

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