Bond Strength between Steel Reinforcement and Grouted Splice Sleeve Connector

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Abstract. The use of precast concrete system is now widely regarded as an economic, structurally sound and architecturally versatile form of construction. Structures which were previously made only with cast-in-situ concrete are now being constructed using precast concrete. However, if a precast connection is not properly designed, the safety and durability of precast structure could be significantly affected. This study presents the experimental results of bond strength between steel reinforcement bar and grouted splice sleeve connector. In this study, the bond strength value between steel reinforcement and grout is first to be determined and then obtain the relationship between bond strength and slip in the grout based on the graph. The various parameter was used in this research to study the effect of different diameter of SGP Galvanised Iron pipe, different thickness of SGP Galvanised Iron pipe, different embedded length during tensile test and different diameter of steel reinforcement bar. A total of 12 pull out specimens were tested until failure. The results show that the bond performance between steel reinforcement bar and grout improved due to the reducing size of diameter of sleeve and increase the thickness of the sleeve. It has been seen also that the bond strength decreases when the embedded length increases. Specimens in D39 series were resulted stronger bond strength when used the larger diameter of steel bar. Meanwhile, D32 series were resulted that the bond strength were stronger when used the larger diameter of steel bar with longer embedded length and smaller diameter of steel bar with shorter embedded length.

Introduction

Construction in precast concrete is gaining popularity worldwide. Structures which were previously made only with cast-in-situ concrete are now being constructed using precast concrete. The use of precast concrete system is now widely regarded as an economic, structurally sound and architecturally versatile form of construction. However, if a precast connection isn't properly designed, the safety and durability of precast structure could be significantly affected.

Connection in precast concrete structure is very important in ensuring the stability of the structure. The tensile capacity of connection could be achieve by few methods such as bolting, grouting of steel reinforcement at site, or welding. Splice sleeve connector is then introduced. Installation of splice sleeve connector could prevent from steel reinforcement congestion at lap zone and eliminates the occurrence of rock pocket. Rock pocket problem often occur at lapping zone as concrete cannot pass through the space between lapped bar, leaving voids in between which could weaken the structural system as the bonding between reinforcement bar and the surroundings of concrete is weak.

Problem statement

Bonding is the interaction between the contact surface of embedded reinforcement bar and concrete or grout. Bond strength which is also known as bond stress is often related to the some parameter such as roughness of steel bar or diameter of steel bar. Besides that, bond strength is also related to the cement particle. However, the failure mechanism has remained blurry as it occurs within the concrete and cannot be observed physically. Therefore, this research proposes the investigation of different type diameter of Steel Gas Pipe (SGP) Galvanised Iron pipe, different of thickness SGP G.I pipe, different embedded length and different diameter of steel reinforcement bar. The study of this varies parameters allows the understanding of bond mechanism in which the step by step failure mechanism will be observed.

Research Objective

There are basically three objectives of this study :

1. To determine the maximum value of bond strength between steel reinforcement bar and grout of splice sleeve connector.
2. To obtain the relationship between bond strength and slip in the grout.
3. To study the effect of different diameter of SGP Galvanised Iron pipe, different thickness of SGP Galvanised Iron pipe, different embedded length during tensile test and different diameter of steel reinforcement bar.

Scope of study

The scope of this research limited to the study of splice sleeve connector for connecting two steel reinforcement bars, the experimental work was with SGP Galvanised Iron pipe, and different type of thickness SGP Galvanised Iron pipe, different diameter SGP Galvanised Iron pipe, different embedded length and different diameter of steel reinforcement bar

Previous Studies

Bond behaviour of reinforcing steel bars to concrete is one of the most important mechanisms that should be properly designed to ensure satisfactory performance of reinforced concrete structures. The bond strength is affected by many factors, the most important factors are the level of confinement, nominal bar diameter, concrete compressive strength, embedded length, diameter of the sleeve, and rib area on bond strength.

Confinement is one of the factor that affected the bond characteristic. Confinement by the concrete is dependent on the clear concrete covers and the bar spacing, increasing the development or splice length of a reinforcing bar is increases its bond strength. Based on previous research done by Raafat El-Hacha [1], the bond behaviour of steel reinforcement bars was found that any increase in the confinement of the bar by the surrounding concrete there are increases the bond strength and the minimises splitting.

The greater bond strength with smaller bar size was found in research done by Hadi [2]. This is due when the amount of concrete surrounding the reinforcing bar increased, thus the bond strength and the initial stiffness were increased. However, based on the study done by Raafat El-Hacha [1], the bond strength between concrete and steel reinforcement bar increases as the bar diameter increases. Bond strength of bars confined by steel reinforcement bar increases with the increase in the relative rib area.

Based on the research done by Barbosa M.T et al. [3], he state that bond strength was greatly influenced by the strength of concrete. Higher concrete strength would result in higher bond strength. This is supported by Muhammad N.S.H [4], indicated that concrete strength has a high influence on the bond strength. High concrete strength would result in a higher confinement as a high strength concrete has high stiffness. Therefore, the confinement force acting on the reinforcement bar is higher.

Embedded length of the bar greatly affects the bond strength. It has been seen in previous research done by James H.Haido [5], that the bond strength decreases when the embedded length increases. Moreover, the results was been proved in research done by A. Foroughi-Asl et. al. [6], they were observed that the ultimate bond strength is depending on the embedded length. The bond strength decrease when the embedded length increases. Moreover, that lap splice or embedment lengths as short as seven times the bar diameter can achieve bar development when the appropriate grout compressive strength and confinement are provided were found in research done by Einea [9].

According to previous research done by A.Alias [7], an investigation undertaken to study the effect of sleeve diameter on the bonding performance of the sleeve connector. The better bonding performance was found when the connectors with a smaller external and internal sleeve diameter appear in the tensile test results. This results also were proved by previous research done by Soroushian, P [8], they were investigated the local bond stress behaviour of deformed bars in confined concrete. They concluded that the bond strength decreased linearly as the sleeve diameter increased.

Methodology

The purpose of this study was to investigate the bond mechanism within the splice sleeve connector. The research involved 12 specimens with various parameters such as different diameter and thickness of SGP G.I pipe, different embedded length and different diameter of steel reinforcement bar. For easy reference, the specimens are divided into two series, namely D39 and D32. The names of series are based in the diameter of SGP G.I Pipe. A total 6 specimens were considered in each of series test. Figure 1 shows the component of splice sleeve connector.

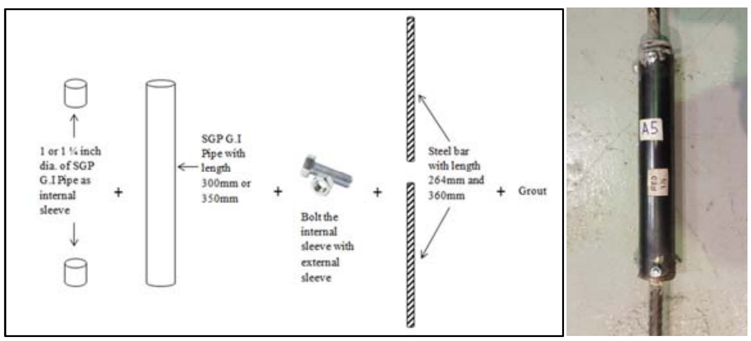

Figure 1: The component of splice sleeve specimen.

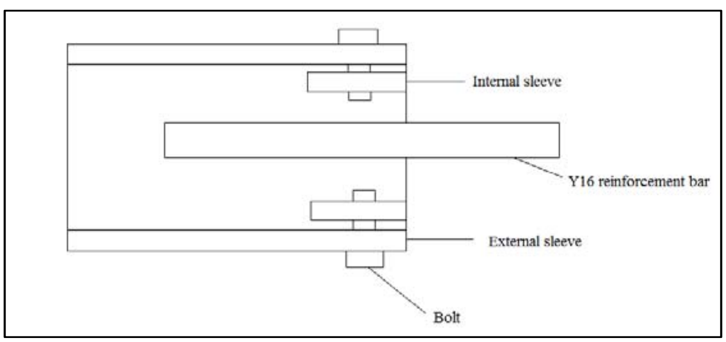

Figure 2: Detail of Cross Section Specimen

Table 1: The details for D39-series are summarized as follows:

Specimen	Internal Diameter of Sleeve (mm)	External Diameter of Sleeve (mm)	Thickness of SGP G.I Pipe (mm)	Embedded Length (mm)	
D39T2.0L64	32	39	2.0	64	4d
D39T2.0L160	32	39	2.0	160	10d
D39T3.2L64	32	39	3.2	64	4d
D39T3.2L160	32	39	3.2	160	10d
D39T4.0L64	32	39	4.0	64	4d
D39T4.0L160	32	39	4.0	160	10d

Table 2: The details for D32-series are summarized as follows:

Specimen	Internal Diameter of Sleeve (mm)	External Diameter of Sleeve (mm)	Thickness of SGP G.I Pipe (mm)	Embedded Length (mm)	
D32T2.0L64	25	32	2.0	64	4d
D32T2.0L160	25	32	2.0	160	10d
D32T3.2L64	25	32	3.2	64	4d
D32T3.2L160	25	32	3.2	160	10d
D32T4.0L64	25	32	4.0	64	4d
D32T4.0L160	25	32	4.0	160	10d

Materials

The material is required in this experimental program consisted of steel reinforcement bars, SGP G.I pipes, bolt and nut, grout, angle and the frame which hold the SGP G.I pipes and steel reinforcement bars when process of pouring grout.

Specimen preparation

The SGP G.I pipe was first tied onto the frame before the steel reinforcement bar was inserted into the pipe and tied onto the frame. Steel wires were used to tie the steel reinforcement bars and SGP G.I pipe in position and the bottom part of SGP G.I pipe is covered with plywood filled with silicone to prevent grout from flowing out during grouting.

After the reinforcement bars and pipes were fixed in place on the plywood frames, the grouting was performed. The grout was mixed using a mixer according to the specification as stated. All the grouting works were done manually by pouring the grout into a cone connecting to the pipe. Figure 3 shows assembly of the specimens on the plywood frame.

Figure 3: Assembly of the specimens on the plywood frame

Test plan and setup

Three different test were conducted in this research to study different parameters involved, which are the compression tests on the grout cube, tensile tests on the reinforcement bars and lastly the tensile test on the splice sleeve specimens.

*Compression test.*Cube test was conducted on the cubes before the testing of each specimen to confirm the compressive strength achieved by the grout. The cubes were tested after 7 day and tested by compression machine to obtain an average value of the compressive strength of the grout.

Single – bar tensile test. Tensile tests or also known as tension tests were carried out to determine the average tensile strength of the reinforcement bars. Figure 4 shows single-bar tensile test.

Figure 4: Single-bar tensile test.

Figure 5: Tensile test on the specimen.

Tensile test on the splice sleeve specimens. All the specimens were loaded with incremental axial force by using the same testing machine to failure. The tensile tests were carried out after the grout had been cured more than 7 days, to allow the grout sufficient time to achieve its' target strength. Both upper and lower parts of the specimen were clamped tightly at the machine when tensile test conducted. Figure 5 shows the tensile test on the specimen.

Results and Analysis

Cube compression test

Cube compressive strength test was carried out initially to determine the type consistency of grout mix to be used at grouting pipe stage before tensile test on the splice sleeve specimens. The results of the compressive strength tests will determine the maximum strength of grout mix. The research was carried out using Fosroc Conbextra GP Grout, and there are two types consistency of grout mix which are trowable and flowable. In this research, only one type consistency of grout mix was chosen which was flowable. The six of cube samples were prepared which each two of the cube samples were be tested at fifth day, seventh day and at the day of the tensile test on the splice sleeve specimens was conducted. Table 3 shows the results of Fosroc grout cube compressive strength test. Based on the results, after fifth day, the strength of Fosroc grout managed to exceed 40 N/mm^2 and its shows that all cubes had achieved satisfactory grout strength higher than the target strength of 40 N/mm^2.

Table 3: The results of Fosroc grout cube compressive strength test.

Age of Cube Samples	Cube Sample	Ultimate Stress (N/mm^2)	Average Stress (N/mm^2)
5th days	A1	49.41	47.68
	A2	45.95	
7th days	B1	55.53	54.90
	B2	54.26	
Day during the Tensile test	C1	61.34	61.50
	C2	61.65	

Tensile test of reinforcement bar Y16

For the control specimen, a steel reinforcement bar Y16 with a diameter of 16mm was subjected to tensile loading until failure. The ultimate tensile load for the steel reinforcement bar is tabulated in Table 4. The corresponding load versus displacement of the Y16 bar is shown in the Figure 6.

Table 4: Result for tensile test for Y16 steel reinforcement bar.

Sample	Tensile Load, P (kN)	Displacement, mm
Y16	132	60.4

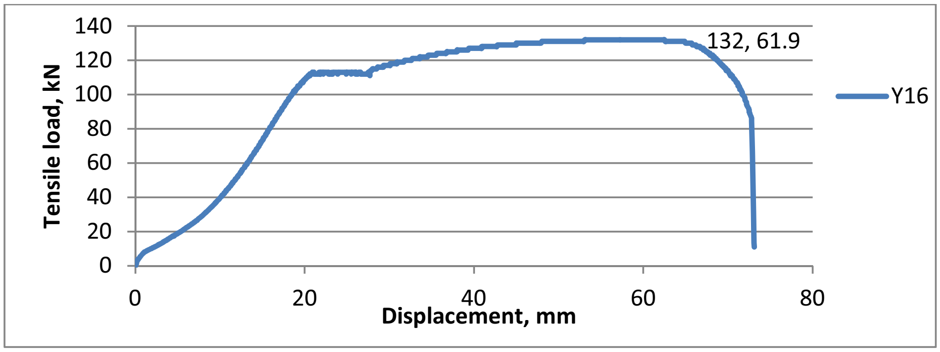

Figure 6: Graph of tensile load against displacement for Y16.

Summary of test results for all the specimens.

Table 5 shows the summary of ultimate tensile load, bond strength, slip with failure modes of all specimens. Figure 7 shows the corresponding 3 failure modes i.e. a) Grout-bar bond failure; b) Bar tensile failure; c) Internal sleeve failure. Subsequently, Figure 8(a) and Figure 8(b) show the corresponding response of tensile load versus displacement, Figure 9(b) and Figure 9(b) show the corresponding response bond stress versus slip for D39 series and D32 series.

Table 5: Summary of test result with ultimate tensile load, bond strength, displacement with mode of failure

Series	Specimen	Ultimate Tensile Load, (kN)	Bond Strength, (N/mm^2)	Displacement, (mm)	Failure mode
D39	D39T2L64	73.400	22.813	7.430	Grout-bar bond failure
	D39T2L160	128.000	15.913	18.710	
	D39T3.2L64	62.460	19.413	5.480	
	D39T3.2L160	129.000	16.038	18.130	
	D39T4L64	68.700	21.353	6.100	
	D39T4L160	137.000	17.032	27.160	
D32	D32T2L64	67.333	20.928	6.380	Grout-bar bond failure
	D32T2L160	138.000	17.157	35.870	Bar tensile failure
	D32T3.2L64	47.080	14.633	5.900	Grout-bar bond failure
	D32T3.2L160	83.700	10.406	8.780	Internal sleeve failure
	D32T4L64	87.700	27.258	8.470	Grout-bar bond failure
	D32T4L160	138.000	17.157	31.250	Bar tensile failure


a) Grout-bar failure


b) Bar tensile failure


c) Internal sleeve failure

Figure 7: Failure modes

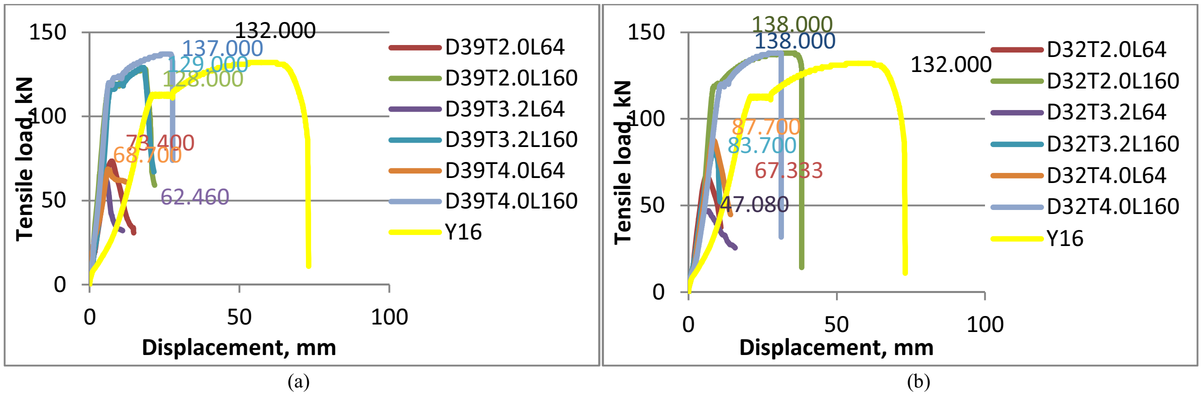

Figure 8: Graph tensile load versus displacement for (a) D39 and (b) D32 series

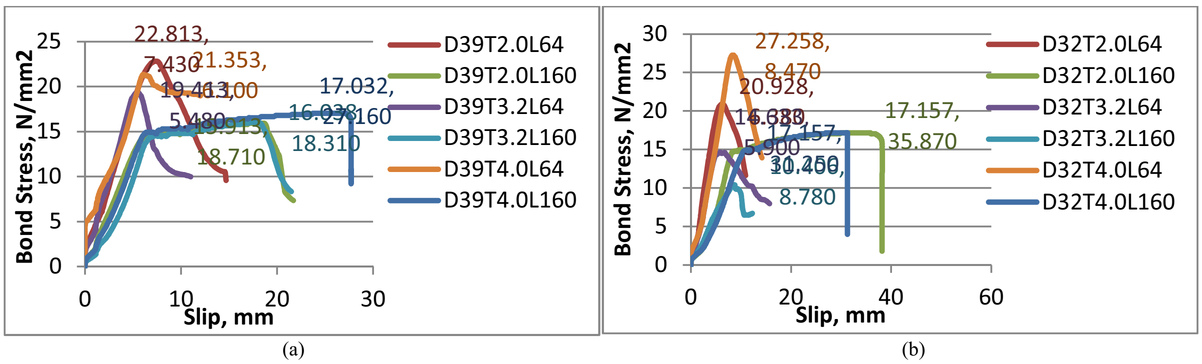

Figure 9: Graph bond stress versus slip for (a) D39 and (b) D32 series

From the test results shown from Table 5, few general patterns can be observed such as follows:

1. The bar tensile failure only occurred when sufficient embedded length of reinforcement is provided on the connectors which is 160mm in D32 series.
2. The varying factors of different thickness of SGP G.I Pipe used in the research for D39 series do not have vital impact on the failure mode of the connectors.
3. The internal sleeve failure only occurred when bolt and nut was failed to connect the internal sleeve and external sleeve.
4. For D32 series, when embedded length of reinforcement is 64mm, the grout-bar bond failure was occurred.
5. The bond strength higher when the embedded length was smaller. However, the ultimate tensile load was lower when the embedded length was smaller.
6. The safe value of bond strength is 16.5 N/mm^2.
7. Grout splice sleeve consist of higher level of stiffness for bond stress before the slip value was approximately 8.5mm. Bond stress become weaker as the slip value exceeded approximately 8.5mm.
8. The grouted splice sleeve connector for specimen D39T4L160, D32T2L160 and D32T4L160 can be classified as a satisfactory connector as the connector is able to generate tensile strength equal to or higher than the tensile capacity of the control bars.

Effect of the parameters

This section explains the effect of different parameters on the results of the splice sleeve connector. The parameters consist of diameter size of SGP G.I Pipe, thickness of SGP G.I pipe, embedded length of reinforcement bar and size of reinforcement bar.

Effect of the parameters varied in diameter size of SGP G.I Pipe. Based on Figure 10, the bond strength of the D32 series, for specimens T2L160, T4L64 and T4L160 were 17.157 N/mm2, 27.258 N/mm2 and 17.157 N/mm2 which were higher than specimen of D39 series, namely specimens T2L160, T4L64 and T4L160. This result could be due to the increase of confining pressure, as the external and internal diameter of the sleeve connector for D32 series were smaller than D39 series. 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 movement of the grout, thus resulting in a high compressive stress at the interface of the sleeve, particularly between the internal sleeve and grout. This result is in line with results of previous research done by [7] and [8], as they concluded that the bond strength decreased linearly as the sleeve diameter increased.

However, the bond strength of the D32 series, for specimens T2L64, T3.2L64 and T3.2L160 were lower than D39 series, namely specimens T2L64, T3.2L64 and T3.2L160. This result might be due to the improper self-compaction that can cause presence of voids in grout sleeve. Therefore, it will caused the bond strength to become weaker as the diameter of sleeve decrease.

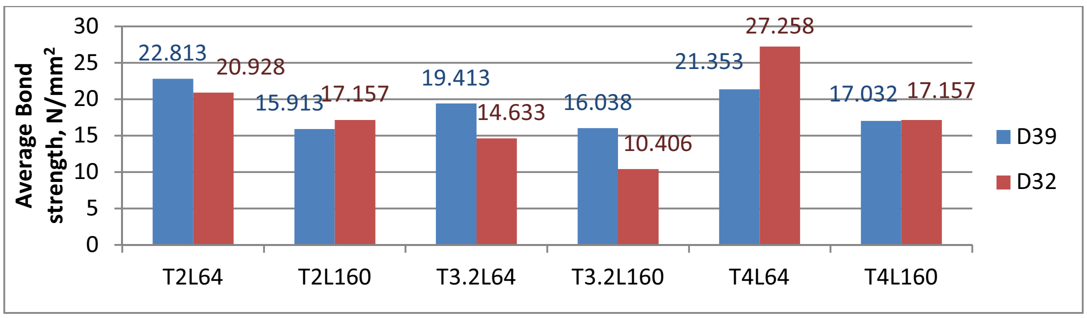

Figure 10: Graph of bond strength based on all specimens for effect different diameter of sleeve.

*Effect of the parameters varied in thickness of SGP G.I Pipe.*Based on Figure 11, the bond strength for specimens with thickest which is 4mm have a higher bond strength between thickness of 3.2mm and 2mm. Apparently, the thickness of the pipe gave significant effect to the bond strength performance in this situation. According to the result, specimens D39L160, D32L64 and D32L160 with thickness pipe of 4mm have stronger bond strength compared to the thickness pipe of 2mm and 3.2mm. This might be because the load transfers mechanism between the grout and the pipe through chemical bond or friction is relatively strong.

However, only specimen D39 L160 shows the bond strength increase gradually when the thickness of sleeve is increased from 2mm to 4mm which are 15.913 N/mm2 to 17.032 N/mm2. The bond strength increased, when the thickness of the pipe increased. This result might be due increase the in radial strength, sleeve stiffness, and confinement pressure, which prevented the propagation of radial cracks and expansion of grout.

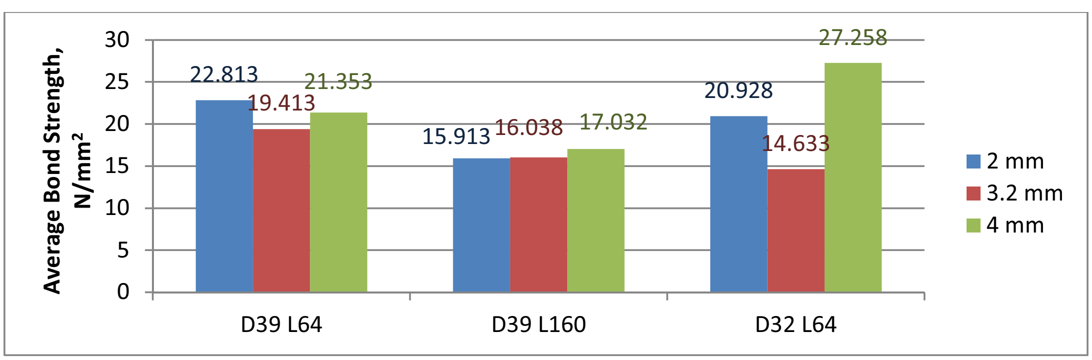

Figure 11: Graph of bond strength based on all specimens for effect different thickness of pipe.

Effect of the parameters varied in embedded length of steel reinforcement bar. Figure 12 shows the variation of bond strength of grout with steel reinforcement bars of 64mm embedded length and bars of 160mm embedded length respectively. It was observed that the embedded length of the bar greatly affects the bond strength. According to the test result shown above, it has been seen that the bond strength decreases when the embedded length increases. This result was supported by previous research done by [5] and [6], as they concluded that the bond strength decreased as the embedded length increased.

From other point of view, the specimen in D32 series with reinforcement bar of 160mm embedment length failed with bar fractured. In this research, the effective embedded length of reinforcement, Le = embedded length of Y16 steel bar – the length of shear key shear key steel pipe (25mm). Hence, the effective embedded length for D32 series is 135mm and approximately 8 times the reinforcement bad diameter. From the result, it is observed that only D32 series with embedded length 160mm were failed with bar fractured while D39 series failed with grout-bar failure, thus in this case, the diameter of pipe does influence the embedded length of reinforcement bar.

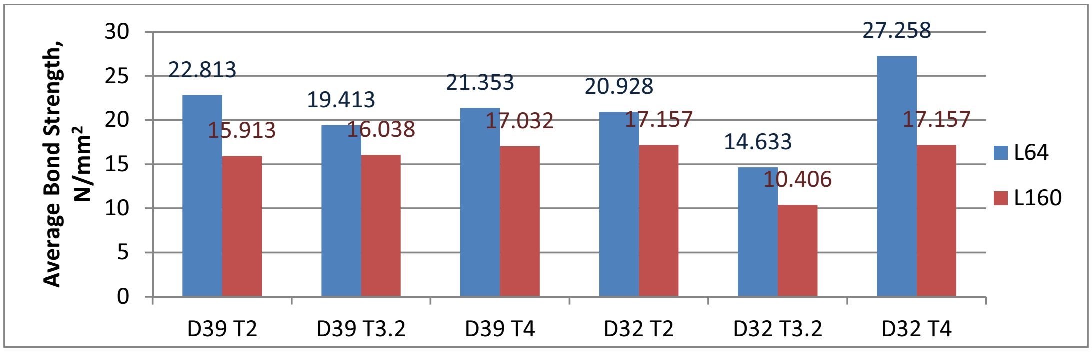

Figure 12: Graph of bond strength based on all specimens for embedded length of steel reinforcement bar.

*Effect of the parameters varied in diameter of steel reinforcement bar.*This section explains the effect of different diameter of steel reinforcement bar. The results of Y12 shown in Figure 13 and Figure 14 were obtained from current studies, “Effects of confinement of tubular pipe to bond stress between deformed steel bar and grout”.

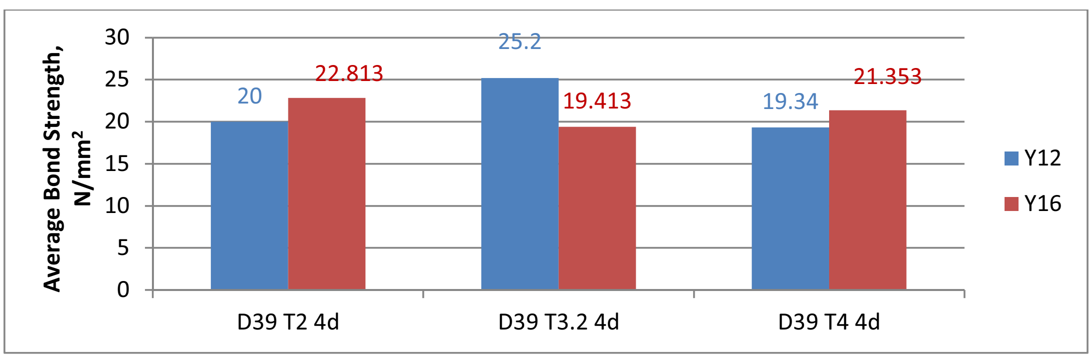

Figure 13: Graph of bond strength based on all specimens for different diameter of steel reinforcement bar for D39 series.

Based on Figure 13, the bond strength of specimens D39T24d and D39T44d were stronger when the larger the diameter of steel bar and it is different with the result of specimen D39T3.24d. This might be due to bond strength of bars confined by steel reinforcement bar increases with the increase in the relative rib area. Therefore, according to the result, the specimens in D39 series have stronger bond strength when used the larger diameter of steel bar.

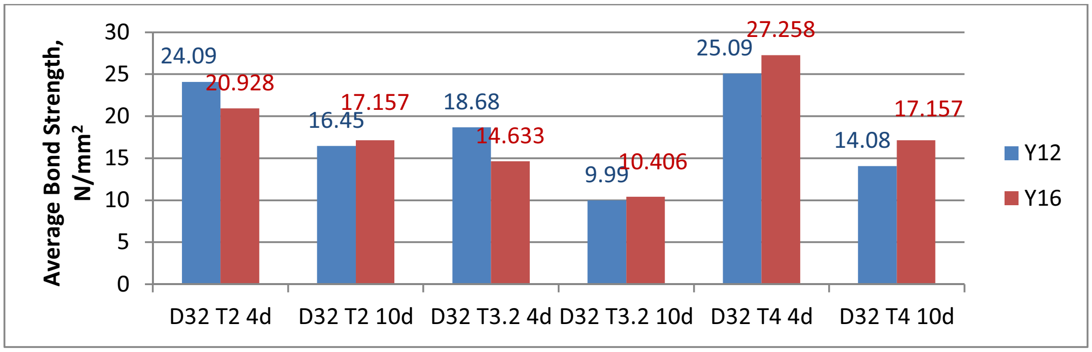

Figure 14: Graph of bond strength based on all specimens for different diameter of steel reinforcement bar for D32 series.

Based on Figure 14, most of the specimens results shows that the bond strength of specimens stronger when larger the diameter of steel bar in D32 series. This might be due to bond strength of bars confined by steel reinforcement bar increases with the increase in the relative rib area.

However, the bond strength of specimens D32T24d and D32T3.24d were stronger when smaller the diameter of steel bar and it is different with other specimens. This could be because shorter embedded length is more suitable used with smaller diameter steel bar.

Therefore, according to the result, most of the specimens in D32 series were resulted that the bond strength were stronger when used the larger diameter of steel bar with longer embedded length and smaller diameter of steel bar with shorter embedded length.

Conclusion

From the result obtained, a few conclusions can be found out. The conclusions that can be drawn down from studying the difference configurations specimens are as follows:

Objective 1

1. The maximum value of bond strength for D39 series is 22.813 N/mm^2.
2. The maximum value of bond strength for D32 series is 27.258 N/mm ^{2}.

Objective 2

1. Grout splice sleeve for D39 series showed higher level of stiffness of bond stress at the slip value approximately 7.4 mm. Bond stress become weaker as the slip values exceeded 7.4 mm.
2. Grout splice sleeve for D32 series showed higher level of stiffness of bond stress at the slip value approximately 8.5mm. Bond stress become weaker as the slip values exceeded 8.5 mm.

Objective 3

1. The diameter of the sleeve gives significant effect over the bond strength performance. The smaller the diameter of the sleeve, the higher is the bond strength. The connectors with smaller diameter of external and internal sleeve led to increase of confining pressure.
2. The thickness of the sleeve also gives significant effect over the bond strength performance. The thicker the pipe, the higher is the bond strength. From this study, the thickness steel pipe of 2 mm already sufficient to provide enough bond strength due to bar fractured failure occurred on the specimen with thickness of 2 mm.
3. The embedded lengths of reinforcement bar give significant effect over the bond strength performance. In the case of 32 mm sleeve, the effective embedded length of 135mm which is approximately 8 times the reinforcement bar diameter is adequate to provide full tensile strength of the connected rebars.

4. The larger the diameter of connected rebar, the higher is the bond strength. Bond strength of bars confined by steel reinforcement bar increases with the increase in the relative rib area.

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