Journal of Mechanical Engineering and Sciences (JMES)
ISSN (Print): 2289-4659; e-ISSN: 2231-8380; Volume 7, pp. 1094-1102, December 2014

DOI: http://dx.doi.org/10.15282/jmes.7.2014.8.0106

PERFORMANCE OF GROUTED SPLICE SLEEVE CONNECTOR UNDER TENSILE LOAD

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ABSTRACT

The grouted splice sleeve connector system takes advantage of the bond-slip resistance of the grout and the mechanical gripping of reinforcement bars to provide resistance to tensile force. In this system, grout acts as a load-transferring medium and bonding material between the bars and sleeve. This study adopted the end-to-end rebars connection method to investigate the effect of development length and sleeve diameter on the bonding performance of the sleeve connector. The end-to-end method refers to the condition where reinforcement bars are inserted into the sleeve from both ends and meet at the centre before grout is filled. Eight specimens of grouted splice sleeve connector were tested under tensile load to determine their performance. The sleeve connector was designed using 5 mm thick circular hollow section (CHS) steel pipe and consisted of one external and two internal sleeves. The tensile test results show that connectors with a smaller external and internal sleeve diameter appear to provide better bonding performance. Three types of failure were observed in this research, which are bar fracture (outside the sleeve), bar pullout, and internal sleeve pullout. With reference to these failure types, the development length of 200 mm is the optimum value due to its bar fracture type, which indicates that the tensile capacity of the connector is higher than the reinforcement bar. It is found that the performance of the grouted splice sleeve connector is influenced by the development length of the reinforcement bar and the diameter of the sleeve.

Keywords: Grouted; sleeve connector; tensile load.

INTRODUCTION

Lapping of reinforcement bars is common practice in cast-in-situ concrete structures to ensure the continuity of reinforcement bars to transfer the load when sufficient bonding strength is developed at the lapping area. This method, however, may lead to rebar congestion when applied to a precast concrete structure. Furthermore, in particular conditions, the lapping of reinforcement bars is sometimes impractical to use, i.e., when the need for connecting between existing reinforcement bars and a new one is limited by the short development length available. The use of a mechanical connector provides an alternative method to ensure the continuity of reinforcement bars in concrete structures. A mechanical connector system can be defined as a system that utilizes all components to facilitate the coupling of steel reinforcement bars, e.g. a steel sleeve-grout system [1].

In this study, the mechanical connector is a grouted splice sleeve connector where the connector utilizes a mild steel pipe filled with non-shrinkage cement grout as the bonding material to splice the reinforcement bars. The connector will receive a reinforcing bar at each end and meet at mid-length as the grout is poured or injected into the sleeve, as shown in Figure 1. The grouted splice sleeve connector can be used to connect precast elements such as in a precast concrete structure. The application of the grouted splice sleeve connector in a precast concrete structure as the connection system can accelerate the speed of erection, significantly reduces the required rebar lap length, and guarantees higher quality assurance [2]. The idea of using cement grout and steel pipe was suggested to splice deformed bars [3]. Several studies have used various types of material for the sleeve, such as an aluminium sleeve, fibre-reinforced polymer tubes, or polyvinyl chloride pipe (PVC) [4, 5]. Cement grout has been utilized for multiple functions such as sealing cracks or voids in concrete structures as well as filling material for rock-bolt anchors in mining or tunneling [6].

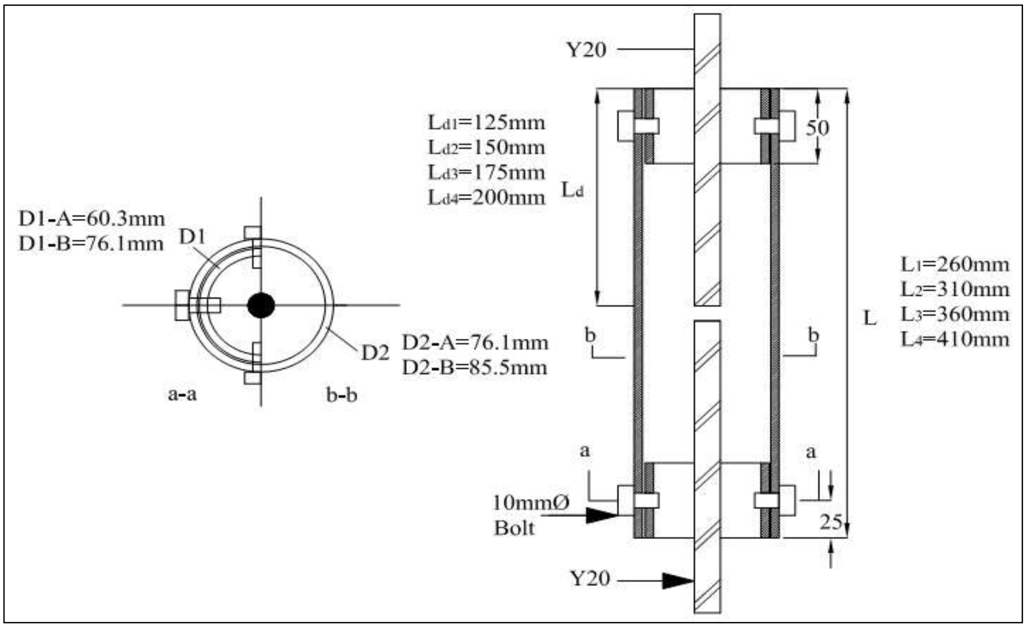


Figure 1. Detailing of grouted splice sleeve connector.

The connector relies on the bonding mechanism between the reinforcement bar and the grout to ensure the continuity of reinforcement bars and sufficient bonding strength generated to transfer the loading. This is done by taking advantage of the bond-slip resistance of grout and mechanical gripping to provide tensile resistance. The strength of the grouted sleeve connector can be influenced by the confinement, diameter and thickness of the sleeve, the compressive strength of the grout, the development length and diameter as well as the type of rebar used, where all of these will contribute to the bond strength between the grout and rebar [3, 7-12]. It is important to prevent slippage of reinforcing bars [8]. Ideally, the bond strength of the connector should be greater than the tensile strength of the reinforcement bar to prevent slippage. In order to increase the bond strength, several available connectors have been produced with complex geometry, where most of the connectors are under proprietorship so information on the behaviour of the connectors is quite limited, as mentioned by Ling, and Abd Rahman [13]. Hence, the objectives of this study are to investigate the effect of development length of reinforcement bars and sleeve diameter on the performance of a steel grouted splice sleeve connector and to determine the possible types of failure.

EXPERIMENTAL SET-UP

Design of Experiment

In this study, eight specimens of grouted splice sleeve connector and one solid reinforcement bar (control specimen) were tested under tensile load. Circular hollow section (CHS) steel pipe with 5 mm thickness was chosen as the external sleeve and internal sleeves. 20 mm diameter high-yield reinforcement bars were used as the reinforcement bar, while non-shrink grout was used as the bonding material. The specimens were divided into two types, namely Type A and Type B (see Figure 1 and Table 1). The internal sleeves were positioned at both ends in the external sleeve and connected with four M10 bolts. The steel bars were inserted into the sleeve with end-to-end configuration until the desired development length and were spaced approximately 10 mm apart. The grout was mixed at pourable condition using SIKAGROUT-215 and poured manually into the sleeve as the sleeves were positioned vertically tied to a wooden frame (see Figure 2).

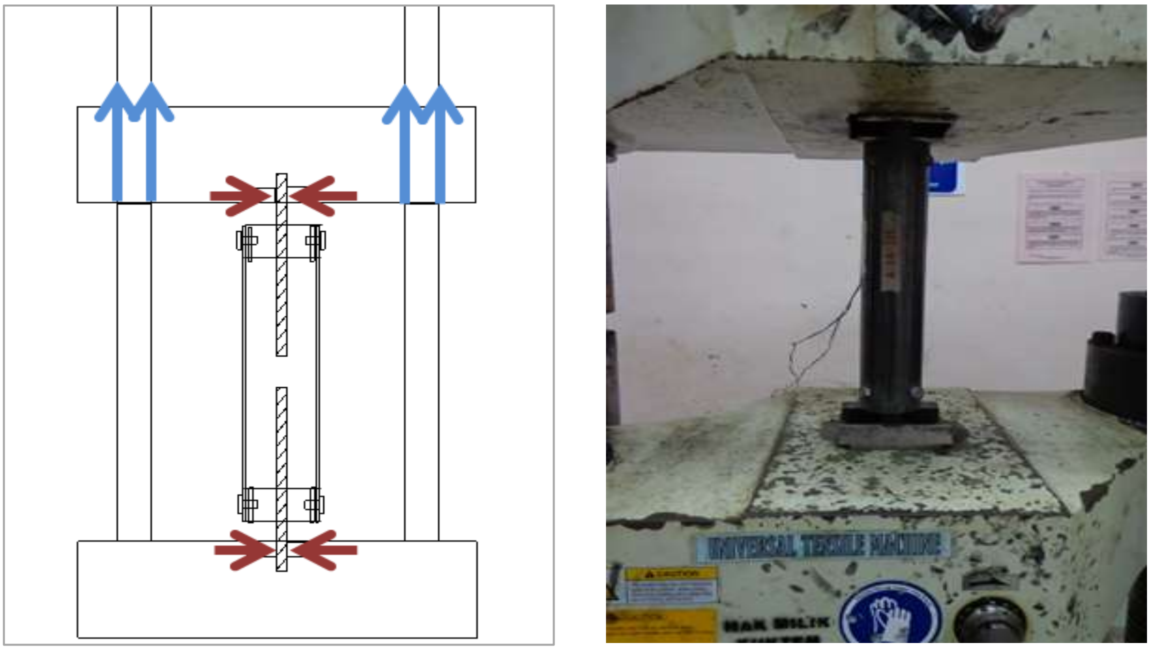
Table 1. Detailed dimensions of grouted splice sleeve connector.

Specimen	External Sleeve (mm)		Internal Sleeve (mm)		Development Length (mm)
	Diameter	Length	Diameter	Length	
Control Bar	-	-	-	-	600
A-20-125	76.1	260	60.3	50	125
A-20-150		310			150
A-20-175		360			175
A-20-200		410			200
B-20-125	85.5	260	76.1	50	125
B-20-150		310			150
B-20-175		360			175
B-20-200		410			200

Figure 2. Grouted splice sleeve connector tied to wooden frame.

Experimental Procedure

As observed in Figure 3, the specimens were tested under incremental tensile load until failure by using a Universal Testing Machine [14] after 7 days of curing, where the average compressive strength of the grout was 46 N/mm^2. The tensile force applied to the connectors was at an average rate of 0.06kN/s. The load variation against displacement was recorded during the test. The tensile test results were then plotted in a load-displacement graph to determine the ultimate tensile capacity (P_u).



(a) (b)

Figure 3. Experimental set-up: (a) schematic diagram; (b) connector on UTM.

RESULTS AND DISCUSSION

The results of tensile capacity for all specimens were illustrated using a load-displacement graph as shown in Figure 4 and tabulated in Table 2. From Figure 4, the result shows that the tensile capacity (P_u) of each specimen increased as the development length increased. The tensile capacity of the Type A connector increased from 162.594 kN to 200.469 kN, while Type B increased from 159 kN to182.3 kN as the development length increased from 125 mm to 200 mm. The ultimate tensile strength of the control bar obtained in this research was 207.281 kN. The slope of the load-displacement graph represents the stiffness of the connector and it shows that the stiffness of the connectors was lower than the stiffness of a single rebar under tensile load. However, the stiffness of the connectors improves as the development length increases. All the connectors endured tension loading and reached the yield point, which indicates that the connector was able to perform more than the elastic limit and continue to provide resistance in the plastic condition before failing in various modes of failure.

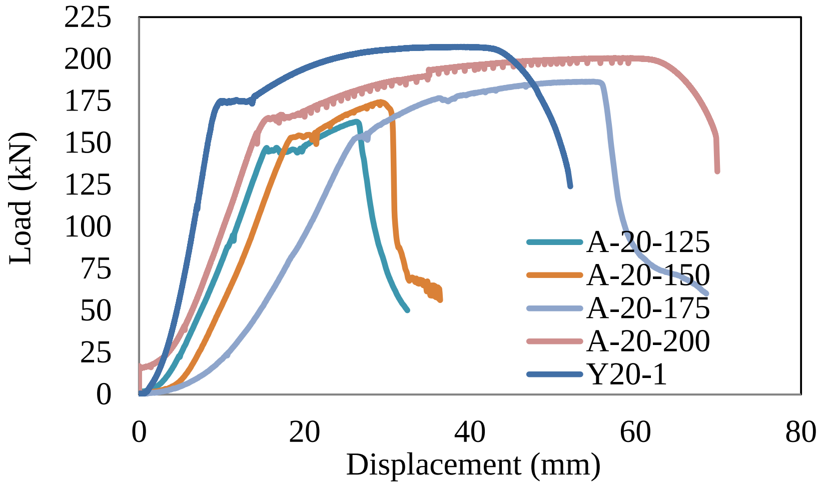
The grouted splice sleeve connector can be classified as a satisfactory connector if the connector is able to generate tensile strength equal to or higher than the tensile capacity of the control bars. Alternatively, a satisfactory connector can be determined from its type of failure, where the failure should be due to bar fracture outside the sleeve or, as stated in ACI 318-71, the ultimate tensile strength (f_u) of the connector must be more than 25% of the specified yield strength ($1.25f_{y,s}$) where $f_{y,s}$ is equal to 460 N/mm^2. The ultimate tensile strength (f_u) can be determined from Eq. (1), where *d* is the diameter of the rebar.

$$f_u = 4 \cdot p_u / (\prod \cdot d^2) \tag{1}$$

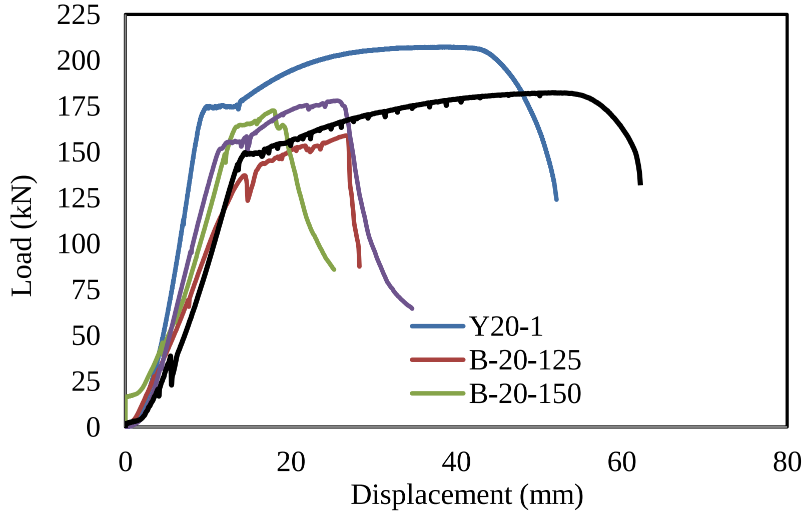
From the experiment, there were three types of failure: i) grout–bar failure; either bar pullout from the grout or internal sleeve pullout together with the grout and rebar and ii) bar fracture outside the sleeve (see Figure 5). The types of failure also changed with respect to the development length; as the development length increased from 125 mm to 200 mm the failure also changed from grout–bar failure to bar fracture. Of eight connectors, only two connectors failed by bar fracture, namely A-20-200 and B-20-200, both of which had the longest development length at 200 mm, whereas the other connectors failed due to grout–bar failure. These two connectors and the A-20-175 connector were able to generate tensile resistance of more than $1.25f_{y,s}$ but the A-20-175 failed due to bar pullout and thus cannot be considered as satisfactory, unlike the A-20-200 and B-20-200 connectors. Connector failures in bar fracture mode were attributed to the larger shear area between the grout and rebar, which caused the bond strength to become stronger as the development length increased. Connectors that failed due to grout bar failure were the result of short development length. This caused the shear-resisting area between the rebar and grout to be inadequate, which led to bar pullout and resulted in the connectors failing due to bond failure The inability of the connectors to generate sufficient bond stress meant they failed to prevent the spliced bar from being pulled out.

Table 2. Tensile test result of grouted splice sleeve connector.

Specimen	Pu (kN)	fu (N/mm2)	fu/fy,s (ACI 318) >1.25fy,s	*Ld / Øbar (BS 8110 =40Ø)*	*Mode of Failure*
Control Bar	207.3	659.86	1.43	-	*Bar fracture*
A-20-125	162.6	517.57	1.13	*6.3Ø*	*Bar pullout*
A-20-150	174.3	554.81	1.21	*7.5Ø*	*Bar pullout*
A-20-175	186.5	593.65	1.29	*8.8Ø*	*Bar pullout*
A-20-200	200.5	638.21	1.39	*10Ø*	*Bar fracture*
B-20-125	159.0	506.11	1.10	*6.3Ø*	*Internal sleeve pullout*
B-20-150	172.6	549.40	1.19	*7.5Ø*	*Internal sleeve pullout*
B-20-175	178.0	566.59	1.23	*8.8Ø*	*Bar pullout*
B-20-200	182.3	580.28	1.26	*10Ø*	*Bar fracture*



(a)



(b)

Figure 4. Load-displacement graph of connectors: (a) Type A; (b) Type B.

(a) (b) (c)

Figure 5. Modes of failure in (a) bar fracture; (b) bar pullout; (c) internal sleeve-grout failure.

From Figure 4 and Table 2, the tensile capacity of the Type A connector, for example, A-20-200, was 200.5 kN, which is 9.94% higher than specimen B-20-200 from Type B. Furthermore, the ratio of f_u to $f_{y,s}$ for Type A connectors is also slightly higher than for Type B connectors. This result could be due to the increase of confining pressure, as the external and internal diameter of the sleeve connector for the A-20-200 connector was smaller than for B-20-200. 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 6). 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 [10]. Eventually, the bond strength increases as the small reduction in sleeve diameter, combined with the effect of the compressive stress generated, is sufficient to mobilize grout-confining actions.

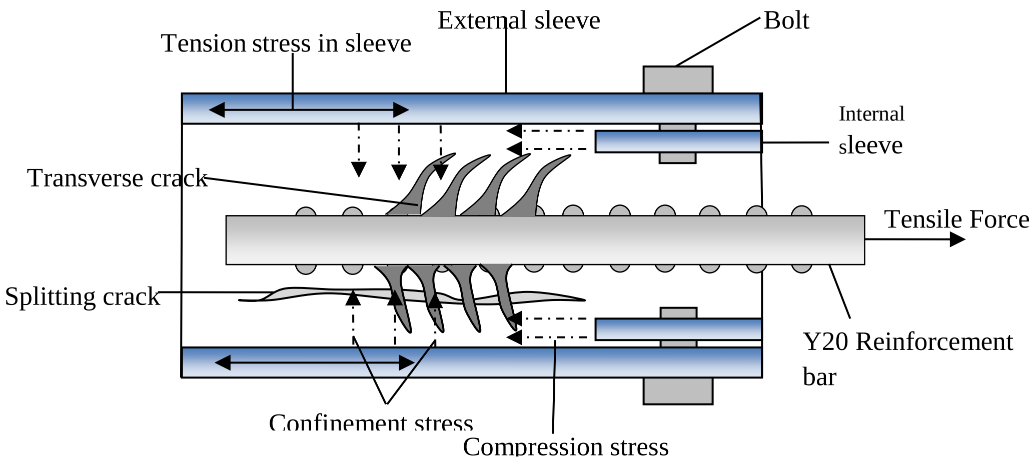


Figure 6. Load transfer mechanism in grouted sleeve connector.

The compressive stress induced by the internal sleeve may also contribute to limiting the propagation of transverse cracks in the grout, thus improving the bonding strength between the grout and reinforcement bars and producing satisfactory connectors. As the spliced reinforcement bar experiences a tensioning state, it transmits the tensile stress to the surrounding grout and the grout transmits it to the sleeve wall. The sleeve wall then generates confinement stress along the inner surface area of the external sleeve wall. This condition will provide a normal pressure or lateral confining pressure to the grout and transmit the pressure to the reinforcement bar, thus increasing the bond strength [15]. The results also show that the application of the grouted splice sleeve connector is able to reduce the minimum required development length of steel bar as stated in BS8110:Part 1, which is 40 times the diameter of the bar (40Ø), to generate enough bond strength (BS8110, 1997). As presented in the results, steel bar with a development length of 200 mm, which is about 10 times the 20 mm bar diameter, was sufficient to provide adequate bond strength by utilizing grouted splice sleeve connectors, as shown by the A-20-200 and B-20-200 connectors. Even though A-20-175 was able to generate tensile resistance of more than $1.25f_{y,s}$ as stated in AC133 and ACI 318-71, with only 8.8Ø of development length, this connector was considered to be undesirable as the mode of failure obtained was bar-pullout, which indicates a bond failure.

CONCLUSIONS

The following conclusions can be drawn from this study:

i. From eight connectors, only two can be considered as satisfactory, since both connectors, namely A-20-200 and B-20-200, were able to comply with the requirement that the connector should be able to withstand tensile stress more than or equal to 1.25 times the specified yield strength, with the mode of failure being a bar fracture outside the sleeve.
ii. The development length of reinforcement bars greatly affects the performance of the connectors, where connectors with 200 mm of development length provide a satisfactory result, with failure due to bar fracture. Development lengths of less than 200 mm are considered inadequate. The development length can be reduced to 10 times the diameter of the rebar, which is less than that 40 times that required in the design standard.
iii. 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 motion from being pulled out and provides some confining pressures.
iv. The two types of failure identified in this study were bar fracture outside the sleeve and grout bar failure (bar pullout and grout-internal sleeve pullout). Bar fracture suggested that the tensile capacity of the connector was higher than the tensile capacity of the reinforcement bar, while bar pullout and grout-internal sleeve pullout indicate low grout–bar bond strength and grout–sleeve bond strength respectively.

ACKNOWLEDGEMENTS

The authors are obliged to Universiti Malaysia Pahang for providing laboratory facilities and financial assistance under project no. RDU130339.

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