PERFORMANCE OF SPLICE SLEEVE CONNECTOR WITH SPIRAL REINFORCEMENT BAR UNDER DIRECT TENSILE LOAD

Shuhaimi Shaedon¹, Ahmad Baharuddin Abd. Rahman², Izni Syahrizal Ibrahim³, Zuhairi Abd. Hamid⁴

¹Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, MALAYSIA
², ³ Dept. of Structure and Material, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, MALAYSIA
⁴ Construction Research Institute of Malaysia (CREAM), Construction Industry Development Board (CIDB), MALAYSIA

Email address of corresponding author: shuhaimi_z@yahoo.com.my

ABSTRACT

A splice sleeve connector is a mechanical coupler that is used to splice two reinforcement bars, ensuring continuity that allows loads to be transferred between them. Feasibility study was conducted onto a series of nine filled PVC pipe splice sleeve connector with spiral reinforcement that were tested under incremental tensile load until failure. The proposed specimens were varied in terms of diameters of the spiral reinforcement bars and the filled material that bonded onto the reinforcement bars. The performance of the proposed specimens was evaluated through their failure modes, namely bars fractured, bar slippage and filled material slippage. The spiral reinforcement and four Y10 bars that are tied together interlocked on the grout that bonded onto the reinforcement bars, preventing it from slipping out of the sleeve. The failure modes observed from the testing signifies the importance of grout-rebar bond, grout sleeve bond, tensile capacity of spliced steel bars and also the tensile capacity of sleeve connector, as they are directly influencing the ultimate tensile resistance of the specimens. This paper also discuss the load resisting mechanism of the specimens under loading in order to acquire essential basis for further research in developing the splice sleeve connector.

Keywords: splice sleeve, bond, connector, spiral reinforcement, failure mode.

1. INTRODUCTION

A grout-filled splice sleeve connector is a specially designed cylindrical coupler that utilizes non-shrinkage grout as bonding material to splice reinforcement bars and to ensure continuity during the load transfer. In order to splice the reinforcement bars, two steel bars are inserted into the sleeve connector from both ends to meet at mid length before high early-strength grout is injected or poured into the sleeve to bond, thus becoming the load transferring medium in the sleeve connector.

A splice sleeve connector can be utilized as connection system in precast concrete wall panels. The splice sleeve connectors are cast together with prefabricated wall panels under controlled environment before they are transported to the construction site for installation. The vertical reinforcement bars are extruded from the upper wall panels at the intended length and embedded into sleeve connectors from the lower wall panels. As the wall panels are placed onto each another during the erection of wall frame system, the extruded steel bars are to be properly inserted into the sleeve connectors in the lower wall panels.

2. LITERATURE REVIEW

The structural performance of the splice sleeve connector is on essential requirement in the precast load-bearing wall system, ensuring integrity and continuity of the precast elements. Ideally, connection systems should not be the weakest points in a wall frame system that can lead to higher stress concentration during the sustained load as it will affect the performance of the global structural system. In
other words, splice sleeve connectors that act as a connection system should not fail before the other structural elements. In higher-rise buildings, flexural failure is more significant as compared to shear failure, due to the action of lateral wind loads and load-displacement effect (P-Δ) of the structures, engaging reinforcement bars to endure high tensile stresses. Basically, for shear resistance, splice sleeve connectors are an advantages as its sleeve can also be utilized to resist shear force instead of relying solely on the effective shear area contributed by the vertical reinforcement bars. Hence, feasibility of splice sleeve connectors as connection system in precast concrete structures is commonly evaluated based on their tensile resistance.

Amin Einea, Takashi Yamane, Maher K. Tadros (1995) found that grout filled splices have been used for the past two decades in the north America, Europe, and Japan to connect precast concrete members. Figure 1 shows an example of common application of grout-filled spliced in wall panels. Sleeves are inserted during the fabrication process on one side of the connection member.

3. METHODOLOGY

In this study, a series of PVC pipe sleeve connectors (AC-Series) with spiral and reinforcement bars was used to splice Y16 bars as an alternative for conventional lapping system. A total of nine specimens, with different spiral diameters were proposed and tested experimentally under incremental tensile load. They were designed to trigger mechanical interlocking effect to the grout, mortar and concrete that bonded onto the reinforcement bars.

Their performance were evaluated based on the load-displacement curve, ultimate tensile capacity, corresponding displacement at ultimate state and failure mode. This was to acquire the feasibility and practicality of the proposed connectors in precast concrete load-bearing wall systems.

Figure 2 and 3 below shows the details and dimensions of the test specimens. High strength Y16 steel bars were spliced in the proposed splice sleeve connectors by using non-shrinkage Sika Grout-215, mortar and concrete as bonding material. The anchorage length of the reinforcement bars embedded in the sleeve was chosen to be 150 mm. The splice sleeve connectors were made of 38 mm, 55 mm, and 75 mm diameters of spiral with 110 mm of diameter PVC pipe as the formwork. Therefore, most of the sleeve connectors were limited at 300 mm length. A group of four Y10 reinforcement bars were tied onto the spiral reinforcement bar vertically. The purpose of the Y10 steel bars and the spiral reinforcement was to provide mechanical interlocking effect to the contact surface between the grout and the splice sleeve
connector, preventing the grout from slipping out of the sleeve.

![Image](image1.png)

**Figure 2**: Details of tested specimens

![Image](image2.png)

Specimen AC-01, AC-04 and AC-07

Specimen AC-02, AC-05, and AC-08

Specimen AC-03, AC-06, and AC-09

**Figure 3**: Detail of tested specimens (spiral reinforcement and Y10 bars)

Figure 4 shows the preparation of the test specimens before the grout was filled. Wooden frames were used to hold the specimens in position before the grout was poured into the sleeve. The Y16 steel bars were inserted into the sleeves from both ends of the sleeve, encountering each other at mid length of the sleeve before they were tied to the wooden frames. All of the specimens were arranged in vertical position while the steel bars were aligned along the central axis of the sleeve. The reason for the reinforcement bars to be aligned at the center of the sleeve connector from the ends, were contact to the other reinforcement bar from the other end at mid span of the sleeve connector. Then, the grout, mortar and concrete at pourable state, was poured into the sleeve by ensuring that the spaces between the reinforcement bars and the sleeves were fully filled.
As the grout hardened and achieved the design strength of 40N/mm$^2$ at 7 days, the specimens were tested under incremental tensile load until failure (Figure 5). The specimens were placed vertically on the platform of the DARTEC hydraulic actuator and gripped onto the steel bars at a pressure of about 11MPa. Then, the actuator’s arm moved gradually upward, inducing tensile force at the rate of 0.5kN/s. The load increment and vertical displacement was recorded during the test.

4. RESULTS AND DISCUSSIONS

4.1 Performance of the Test Specimens

Table 1: Tensile performance of the test specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Material</th>
<th>$f_{cu}$ (N/mm$^2$)</th>
<th>P (kN)</th>
<th>$\Delta L$ (mm)</th>
<th>Failure modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-01</td>
<td>Grout</td>
<td>53.86</td>
<td>83.5</td>
<td>11.688</td>
<td>Grout slipped</td>
</tr>
<tr>
<td>AC-02</td>
<td>Grout</td>
<td>53.86</td>
<td>77.1</td>
<td>12.750</td>
<td>Grout slipped</td>
</tr>
<tr>
<td>AC-03</td>
<td>Grout</td>
<td>53.86</td>
<td>74.6</td>
<td>10.563</td>
<td>Grout slipped</td>
</tr>
<tr>
<td>AC-04</td>
<td>Mortar</td>
<td>25.20</td>
<td>41.1</td>
<td>9.688</td>
<td>Bar slipped</td>
</tr>
<tr>
<td>AC-05</td>
<td>Mortar</td>
<td>25.20</td>
<td>42.8</td>
<td>10.750</td>
<td>Bar slipped</td>
</tr>
<tr>
<td>AC-06</td>
<td>Mortar</td>
<td>25.20</td>
<td>38.7</td>
<td>16.188</td>
<td>Bar slipped</td>
</tr>
<tr>
<td>AC-07</td>
<td>Concrete</td>
<td>30.15</td>
<td>35.3</td>
<td>12.313</td>
<td>Bar slipped</td>
</tr>
<tr>
<td>AC-08</td>
<td>Concrete</td>
<td>30.15</td>
<td>27.5</td>
<td>7.875</td>
<td>Bar slipped</td>
</tr>
<tr>
<td>AC-09</td>
<td>Concrete</td>
<td>30.15</td>
<td>33.7</td>
<td>8.188</td>
<td>Grout slipped</td>
</tr>
</tbody>
</table>
Table 1 summarized the tensile performance of the test specimens, in terms of grout compressive strength, $f_{cu}$, ultimate tensile capacity, $P$ (kN), corresponding displacement at ultimate state, $\Delta L$ (mm), and the types of failure modes. Figure 6 shows the load-displacement curves of the test specimens. The adequate splice sleeve connector could be determined when their spliced steel bars fractured outside the sleeve at ultimate, instead of slipping out of it.

The results show that the tensile resistance of the specimens ranged from 27.5 kN to 83.5 kN, where AC-08 gave the lowest tensile resistance while AC-01 offered the highest ultimate loading capacity. They also recorded relatively high tensile capacities as compared to others.

Based on the results, all specimens, presented unsatisfactory performance because of (a) low tensile capacity, (b) poor ductility, (c) Y10 bar arrangement, (d) material (grout, mortar and concrete). AC-01 Ha higher tensile capacity compared with the other specimens, but it underwent elongation for the spiral reinforcement, indicating the fact that the bond failed before its reinforcement bars yielded. AC-02 and AC-03 failure was due to grout slippage failure, where it underwent bond slippage and low tensile resistance, and AC-04, AC-05, AC-06, AC-07, AC-08 and AC-09 were neither strong in tensile resistance nor ductile during failure. Furthermore, the reinforcement bars of the specimens slipped instead of fractured, indicating insufficient bond strength generated between the filled material (grout, mortar and concrete) and the reinforcement bar to resist the pulling force. Therefore, these specimens were all considered unsatisfactory.

The corresponding displacements of the specimens at the ultimate states listed in Table 1 gave indication of tensile level of the specimens indirectly. The displacement ranged between 7.875 mm and 16.188 mm. It was recorded that all specimens presented fluctuation in load-displacement graphs, indicating yielding process due to extreme tensile stress per unit area to be endured by the steel bars. Meanwhile, all specimens recorded low displacements at ultimate state in Table 1, presented brittle failure. This sudden failure was due to the brittle property of the grout, mortar and concrete. It was either due to (a) poor bond strength between the filled material and the reinforcement bars or (b) poor tensile resistance of the sleeve connector itself, of which was unable to achieve their yielding point of the reinforcement bars.

**4.2 Failure Modes**

Two major modes of failure observed throughout the test. The failure modes provide essential information in this study. Despite of demonstrating the manner of defects of the specimens at ultimate state, they also described the causes of failure that should be taken into account in future development and design of an adequate splice sleeve connector.
4.2.1 Bar Slippage

Figure 7 shows the bond failure of AC-06, which was indicated by the slippage of the reinforcement bars. The spliced steel bars in AC-04, AC-05, AC-06, AC-07 and AC-08 slipped out of the sleeves at 41.1 kN, 42.8 kN, 38.7 kN, 35.3 kN and 27.5 kN respectively. Due to the limited anchorage length of reinforcement bars in the sleeve connectors, i.e. 150mm (for AC-06), the specimens were unable to accumulate sufficient bond stress to resist the spliced bars from being pulled out of the sleeve. The interlock between the bar ribs and the mortar or concrete keys engaged shear areas to resist the pulling force generated by the hydraulic actuator (Figure 8). Insufficient development length led to inadequate shear area to resist the steel bars from slipping out of the sleeve. Beside that, the diameter of the spiral reinforcement and the arrangement of the Y10 also influenced the slippage of the steel bars. Therefore, the steel bars slipped before they achieved their ultimate capacity.

Figure 7: Bar slippage of AC-06

4.2.2 Grout Slippage

It is known that the bond between the reinforcement bars and the grout was mainly contributed by the mechanical interlocking effect between the grout keys, spiral reinforcement, embedded length of the bar and the bar ribs, preventing it from slipping out of the sleeve. Otherwise, the splice sleeve connector would end up like AC-03, where the grout fractured at almost mid length of the sleeve before it slipped out of the sleeve (Figure 9). The specimens failed suddenly at only 74.6 kN tensile load, with the corresponding displacement of 10.563 mm. The results indicate the importance of the bond between the spiral reinforcement and the grout that bonded onto the reinforcement bars, as it could directly influence the tensile resistance of the specimens.
4.3 Factors Governing Tensile Resistance of Specimens

Based on the failure mode, the study found that the tensile resistance of a splice sleeve connector is governed by three major factors, of which the weakest aspect would determine the tensile capacity of the sleeve connector. These factors include grout-rebar bond, material used and arrangement of the spiral reinforcement bar and Y10 steel bar.

4.3.1 Grout-Rebar Bond

The bond between reinforcement bars and grout relies on the interlocking effect between bar the ribs and the grout keys, engaging shear area of the grout keys to resist the pulling force. In this study, the rebar-grout bond failure was due to (a) inadequate development length to accumulate sufficient shear area to resist the slipping force and inappropriate ratio of shear area per unit of bearing area of the bar.

4.3.2 Material

The bond between grout-rebar was better than the bond between mortar-rebar and concrete-rebar. In this study, slippage bar failure occurred (for mortar - AC-04, AC-05, AC-06; for concrete - AC-07 and AC-08) due to the lower strength of the mortar and concrete as compared with the grout strength. Mortar and concrete also have the problem during the casting process due to the small space between the spiral reinforcement and rebar (for the small diameter of spiral; AC-04 and AC-07). Therefore, for concrete it is impossible for the aggregate to pass through spacing of the spiral. Definitely there was no bonding between the spiral, reinforcement bar and the concrete when voids happened during casting process.

4.3.3 Arrangement of the spiral reinforcement bar and Y10 steel bar

In this study, it was observed that the reinforcement bars of the specimens slipped instead of fractured, indicating insufficient bond strength generated between the grout, spiral reinforcement-Y10 bar and Y16 reinforcement bar to resist the pulling force. Therefore, if the Y10 steel bar is arranged in the inner side of the spiral, it can give the good result because of the strength that generated between the reinforcement in the specimens.

5. CONCLUSIONS

In this study, a total of nine specimens experimentally tested under incremental tensile load. The study concluded that:

1. The failure modes observed from the testing consist of bar slippage and grout slippage.
2. The factors that govern the tensile performance of a splice sleeve connector are grout-rebar bond, material used and the arrangement of the spiral reinforcement bar and Y10 steel bars in the specimens. Therefore, these factors must be considered when proposing new splice sleeve connectors.
Specimens AC-01, AC-02 and AC-03 show the higher potential than other specimens because of the higher strength of the grout. So, the proper use of the material are able to generate sufficient bond that could outperform the tensile resistance of the spliced reinforcement bars.

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