Behaviour of Polymer Grouted Splices under Increasing Tensile Load

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Abstract. This paper presents the behavior and performance of polymer grouted splices under increasing direct tensile load. A spiral is utilized to confine the splicing of two discontinued bars which are interlocked within the spiral through the utilization of high strength polymer grout. The bar embedded lengths and the spiral diameters of the grouted splices were varied in order to investigate their effects on the performance of the polymer grouted splices. The performance was evaluated based on the load-displacement relationship, ultimate loading capacity and failure mode. The best performance of polymer grouted splices was obtained with the spiral diameter of 23mm and embedment length of 125mm in which with these parameters the grouted spiral is able to develop the full tensile strength of the spliced bars.

Introduction

In steel reinforced concrete construction it impossible to provide full length continuous bars because of the limited length of commercial bars and the difficulties of interweaving long bars in construction so that splicing of reinforcement bars becomes necessary. Lap splicing is the one of basic ways to splice the bars where two bar ends are lapped side-by-side and wire tied together. The bar ends are of course axially offset which creates design problems, and eccentric loading whether compressive or tensile from bar to bar. [1]. Also, codes require such long laps that steel becomes congested at the splice location; sometimes the laps are truly impossible for lack of room. Other type of splices, in which the reinforcing bars were in tension, is grouted splice. In grouted splice, sleeve is adapted to receive adjoining ends of a pair of reinforcing bars providing confinement for anchorage zone of bar. The bars locked within the sleeve through the utilization of high strength grout to generate an excellent bond so that the intended bond strength can be achieved with a shorter lab length as compared with the conventional bar lapping system. Also, the confinement can be produced by surrounding the splice bars with spirals [2,3], transverse reinforcements [4], cylindrical pipes [5,6,7] and fiber reinforced polymer [8].

These techniques control the propagation of the splitting cracks by resisting the splitting expansion of the bonding materials surrounding the steel bars so provided superior mode of failure compared with lapped splices which is failed by splitting of the surrounding concrete leading to total loss of load-carrying capacity.

Other factors to ensure an excellent bond between bar and surrounding material, the compressive strength of bonding material. High strength grout generates excellent bond so that the intended bond strength can be achieved with a shorter lab length as compared with the conventional bar lapping system. Robins [9] proves that the compressive strength of the bonding material directly influences the average bond stress generated along the bar. Hence, it is realized that the high bond strength generated by the grouted splice was also contributed by the high compressive strength of the bonding material.

Markested andJohansen in 1970 [10] suggested of using steel pipe sleeve with resin mortar with high strength as bonding material for splicing deformed bar. The tests revealed that grouted sleeve splices with polymer grout could be used successfully for splicing reinforcement steel bars.

Recently, there are no available literatures on using polymer grout as bonding material for grouted splices.

In this study, high strength polymer grout is utilized as bonding material for grouted spiral splice. The polymer grouted splice specimens were tested experimentally with the bar embedded length and spiral diameter varied among the specimens to investigate the behaviour of these splices under incremental tensile load.

Methodology

Test specimens

Grouted splice was made of spiral reinforcement with the inner diameters, D*s*, of 23 mm and 33 mm. Four steel bars with the diameter of 10 mm were welded to the outer surface of the spiral to provide ribs for interlocking with the polymer grout that bond to steel bars. The steel bars with, $d_{b,}$ 16 mm diameter were spliced at the embedded lengths, L*e*, of 75 mm, 125 mm and 150 mm (Fig. 1 and Table 1). High strength polymer grout incorporating fly ash with average grout strength is approximately 88.736 N/mm2 after 7 days utilized as a bonding material to hold spliced steel bar within the spiral. Also, three high strength steel bars (Y16) were tested as control specimens.

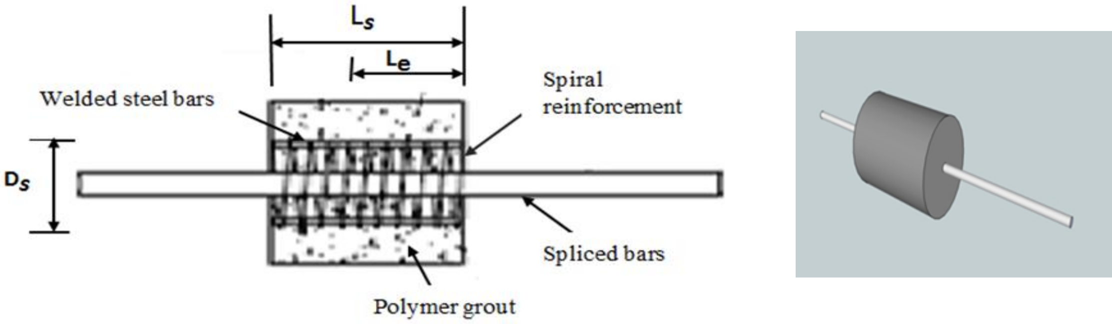

Figure 1: Configuration of polymer grouted splice.

Table 4 details of polymer grouted splices

Specimens	Diameter of spiral (D_S mm)	Length of spiral (L_S mm)	Spliced bar: Embedment of steel bar in grouted splice (L_e mm)	Spliced bar: d_b (mm)
D23-Le75		150	75	
D23-Le100	23	200	100	16
D23-Le125		250	125	
D23-Le150		300	150	
D33-Le75		150	75	
D33-Le1100	33	200	100	16
D33-Le125		250	125	
D33-Le150		300	150	

Test setup

The specimens were tested under incremental tensile load at a rate of 0.128 kN/s using a hydraulic actuator testing machine with a capacity of 250 kN (Fig. 2). Specimens were placed vertically on the platform before applying the load at both ends of the reinforcements. The readings of the applied load and displacement were recorded until failure of the specimen.

Figure 2: Test setup of tensile load.

Test results

Tensile performance

Table 2 summarizes the tensile performance of the polymer grouted splices specimens under incremental load in terms of ultimate tensile capacities, $\mathbf{P_u}$ (kN), corresponding displacements, $\boldsymbol{\delta_u}$ (mm), and also the failure modes. Form this table it is noticed that, for the polymer grouted splices with the same spiral diameter, Ds, and different embedded length, Le, the tensile capacity increases as the bar embedded length increases. As observed from specimens D23-Le75 and D23-Le150, the tensile capacity increased from 74.8 kN to 131 kN due to the bar embedded length, Le, increased from 75 mm to 150 mm. In contrast, for the polymer grouted splices with the different spiral diameter, Ds, and same embedded length, Le, the tensile capacity increases as the spiral diameter decreases. For polymer grouted splices D23-Le125 and D33-Le125, the tensile capacity increased from 69.9 kN mm to 74.8 kN mm as the spiral diameter, Ds, decreased from 23 mm to 33 mm.

Table 2: Tensile performance of the tested specimens.

Specimen label	Ultimate tensile capacity P_u (kN)	Displacement δ_u (mm)	Failure mode
Control Y16 (1)	128	48.4	Bar fracture
(2)	128	42.7	Bar fracture
(3)	128	45.5	Bar fracture
D23-Le75	74.8	16.6	Bar bond-slip
D23-Le100	97.1	20.6	Bar bond-slip
D**2**3-Le125	128	46	Bar fracture
D23-Le150	131	46.3	Bar fracture
D33-Le75	69.9	20.2	Bar bond-slip
D33-Le100	97.8	22.2	Bar bond-slip
D**3**3-Le125	116	26	Welded broken(splitting grout cover)
D33-Le150	113	30.2	Welded broken(splitting grout cover)

Failure Modes

Figure 3: Failure modes; (a) bar bond-slip; (b) bar fracture; (c) grout cover fractured.

Three major modes of failure were observed, namely bar slippage, bar fractured and grout cover fractured as shown in figure 3 (a), 3 (b) and 3 (c) respectively and listed in Table 2. For the specimens D23-Le75, D23-Le100, D33-Le 75and D23-Le100 that fails by bars slipped out of the sleeve provide inadequate bond and failed in brittle manner before yielded of spliced bars as shown in figures 4 and 5. Second, specimens D23-Le125 and D23-Le150 with diameter of 23 and bar embedded length 125 mm or more provide adequate bond and failed in spliced bar fractured outside in ductile manner. The spliced bars in the spiral was yielded and elongated before fracture outside of the spiral. These specimens was able to provide full tensile strength of the connected steel bars and gives larger bar displacement which is mainly contributed by the post-yield elongations of bar as shown in figure 5.

However, there are cases where some of the specimens that failed by grouted cover fracture failure actually failed after yielding of the spliced bars, such as specimens D33-Le125 and D33-Le150. These specimens offered a certain degree of ductility, with the ultimate bar displacements of approximately 26 and 30 mm at failure (refer to Table 2). The weld between the splice bars and spiral failed after the yielding of the bars. As a result, the spliced bars of D33-Le125 and D33-Le150 elongated slightly before failure, and hence, the load-displacement curves of the specimens show a ductile response.

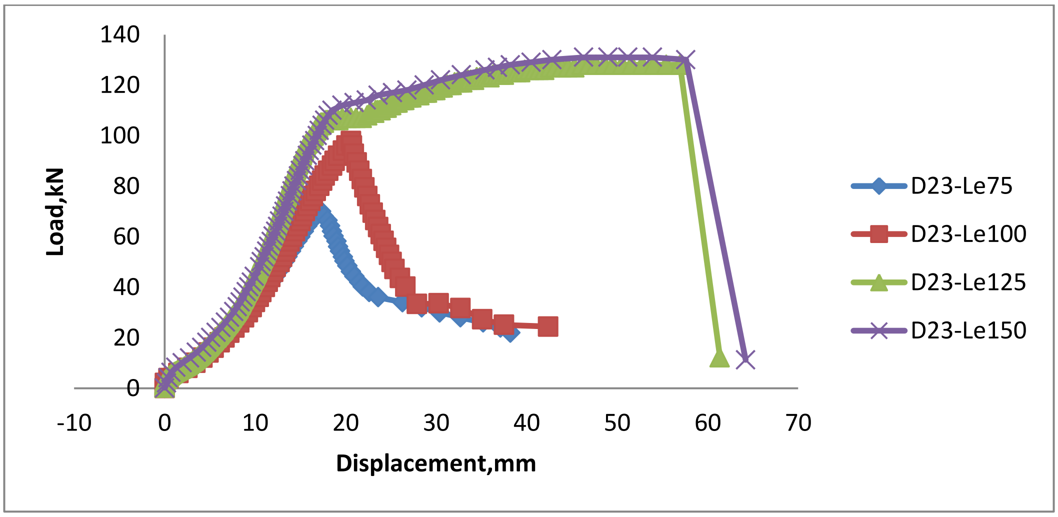

Figure 4: Load-displacement curve of the tested grouted splices specimens (spiral diameter 23 mm)

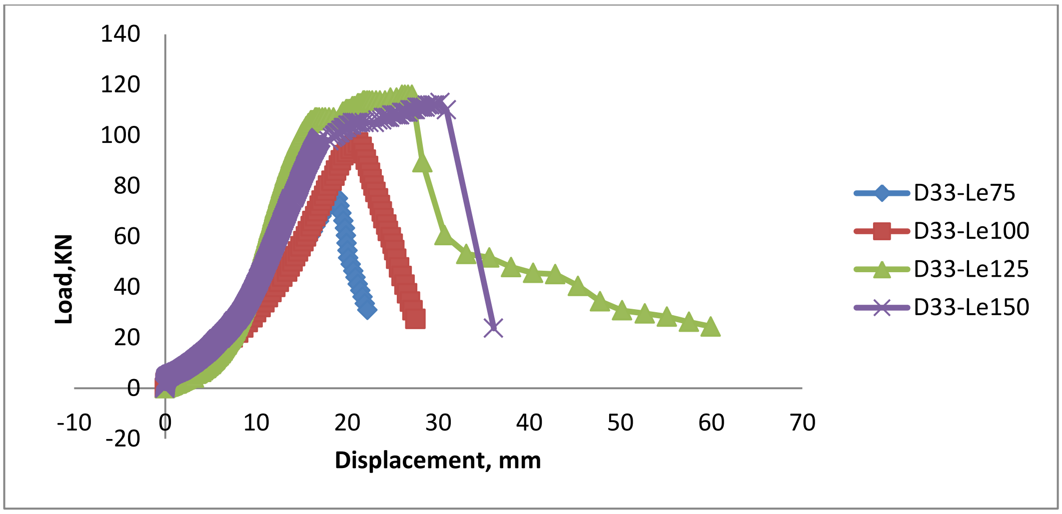

Figure 5: Load-displacement curve of the tested grouted splices specimens (spiral diameter 33 mm)

Conclusion

From the test results several conclusions can be drawn:

1. Tensile capacity of the polymer grouted splices are highly affected by the embedded length of the spliced steel bar and the diameter of the spirals. The tensile capacity increases as the embedded length increases, while these capacity decreases as the spiral diameter increase.
2. The polyester grouted splice with spiral diameter of 23mm and embedded length of 125mm were able to provide full tensile strength of the connected steel bars.
3. For the grouted splice with spiral diameter of 33 mm and embedded length 125 or more, it is realized that the tensile capacity of the grouted splice is governed by the tensile capacity of the spiral, of which, in this study, it yielded and expansion lead to weld broken. So, the performance of grouted splice can be improved by increasing the number of welded reinforcement bar around the spiral.

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