Experimental study of ferrocement for strengthening short lap splice of RC members

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Abstract

This paper presents an experimental program on strengthening short lap splice of reinforcement using ferrocement jacket. The strengthening technique applied the skeleton steel of 9 mm diameter for confining the lap splice zone. The experiment consisted of 7 specimens. One is the control specimen with continuous bar (without lap splice). The other 6 specimens contained lap splice of longitudinal bars. The main study variables were lap splice length and the volume of confining skeleton steel. The ferrocement was made with 50 MPa mortar and reinforced by two layers of hexagonal wire meshes. Based on experimental results, the un-strengthened specimens showed a sudden drop in strength after the peak load capacity was reached. Strengthening by ferrocement jacket could significantly increase the strength by as much as 50% and could develop the yield strength of the bars. Moreover they could also increase the ductility of the strengthened specimens.

Keyword: strengthening, lap splice, ferrocement, bond strength

1. Introduction

In reinforced concrete construction, lap splice of reinforcing bars is commonly used in many locations of the structures, for example, the lap splice of column longitudinal bars and beam longitudinal bars. If the splice length is inadequate for the bond development, the strength and ductility of the members can be degraded [1]. The premature failure of lap splice is normally caused by the splitting of concrete leading to the loss of bond and then the sudden drop in load carrying capacity is observed.

The main factors that affect the bond strength between concrete and steel bars are lap splice length, concrete compressive strength and the concrete cover-to-bar diameter ratio [1-3]. In existing structures, there is an urgent need to retrofit the substandard lap splice to meet the new requirements [4]. There are several methods to retrofit inadequate or short lap splice such as fiber-reinforced polymer (FRP) wrapping [1-3], concrete jacketing [4,5], ferrocement jacketing [6-8] steel plate jacketing [9]. When considering the cost of retrofitting old structures, ferrocement jacketing is a competitive method [10, 11]. In a developing country, i.e., Thailand, ferrocement is a suitable material for use in retrofitting existing structures because it is low-cost, low-skilled labor and the basic materials are readily available throughout the country. Ferrocement is a thin reinforced material with thickness not more than 25 mm. It is made from closely spaced wire mesh and plastered with high cement mortar [6, 10, 12]. The strength can be enhanced by adding skeleton steels made from ordinary steel bars. In this research, the authors apply ferrocement to strengthen lap splice zone.

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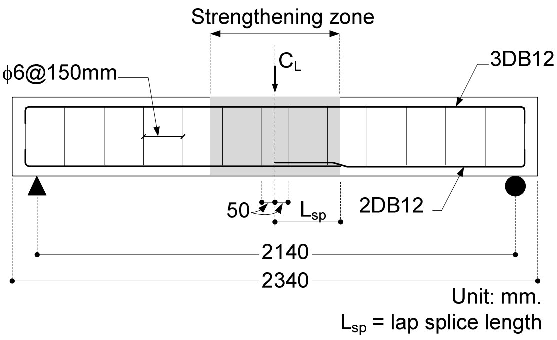
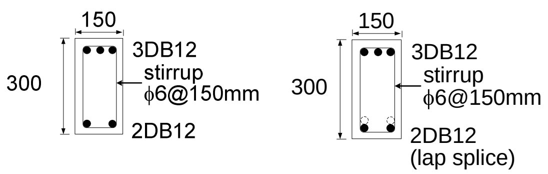
2. Experimental program

2.1 Specimen details

The experiment aimed to study the effect of strengthening lap splice by ferrocement on load and deformation capacity. The main parameters consisted of lap splice length and the technique of ferrocement jacketing. The experiment consisted of 7 specimens. One of them was a controlled specimen without lap splice. The other 6 specimens were divided into two groups, 25db group with 300 mm splice length and 20db group with 250 mm splice length as shown in Table 1. The specimens were beam type with rectangular cross section size of 150x300 mm and the span length of 2140 mm. They were tested under a static point load applied at the center of the beam. The reinforcements in the specimens were 3-DB12 (12 mm diameter) top bars and 2-DB12 bottom bars. The nominal yield strength of the bar is 400 MPa. The specimens also contained stirrups of 6 mm diameter spaced at 150 mm throughout the length of the specimen. The nominal yield strength of stirrup is 240 MPa. The detail of specimen with lap splice is shown in Fig. 1.



a) Specimen's detail



b) control specimen c) specimen with lap splice

Figure 1 Detail of specimens and lap splice

2.2 Strengthening specimens

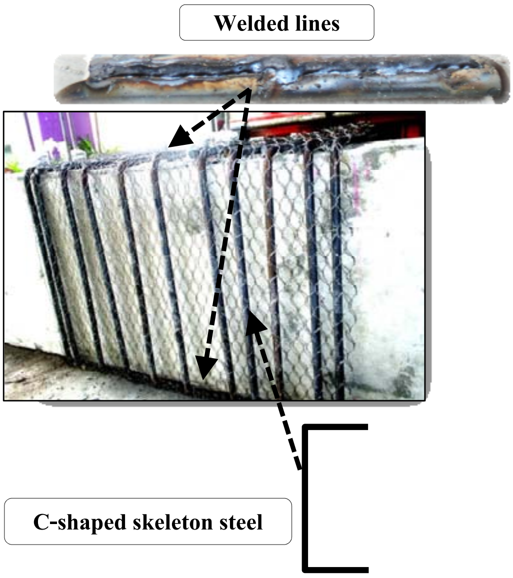
The 20 mm thick ferrocement was jacketed around the specimen in the lap splice zone without preparing surface (see Figure 2). The mortar plaster was high cement content. It was reinforced with 2 layers of hexagonal wire mesh as shown in Figure 3 (a). If the skeleton steel is used, it is recommended that the diameter of skeleton steel should be in range of 3 to 10 mm, and the spacing of skeleton steel should be in range of 50 to 100 mm [13]. In this research, The skeleton steel were plain round bar RB9 (9 mm diameter) with the spacing of 50 mm The skeleton steels were fabricated in 2 C-shaped pieces and assembled to form a loop by welding on both arms of the C-shaped steel as shown in Figure 3 (b).

a) Strengthening of specimen by ferrocement

b) Plastering step

Figure 2 Application of ferrocement

a) Hexagonal wire mesh



b) Skeleton steel

Figure 3 Hexagonal wire mesh and skeleton steel

2.3 Specimen designations

From Table 1, the specimens with lap splice are divided into 2 groups, 25db and 20db. In each group, there were 3 specimens. The lap splice length (L_{sp}) which is equal to the multiple of the number in the series's name and bar diameter (db = 12 mm). For example, 25db will have the splice length equal to 300 mm. The splice length is indicated in column the third of Table 1. The specimen designation is composed of three parts. The prefix number indicates the series (20db or 25db). The letter F indicates specimens with lap splice. The last letter or number indicates the type of retrofit, i.e., "0" indicates no retrofit, "P" indicates the retrofit by hexagonal wire mesh only and "5" indicates the retrofit by 9 mm skeleton steel spaced at 50 mm. The control specimen with continuous bar is designated as "00C1".

Table 1 Specimens designations

Series	List name	L_{sp} (mm)	c/db	Skeleton steel	
				Dia. (mm)	s (mm)
25db	25F0	300	1.7	-	-
	25FP	300	1.7	-	-
	25F5	300	1.7	9	50
20db	20F0	250	1.7	-	-
	20FP	250	1.7	-	-
	20F5	250	1.7	9	50
without lap splice	00C1	-	1.7	-	-

Notes: "c/db" is cover to bar diameter, "Dia." is diameter of skeleton steel and "s" is spacing of skeleton steel

2.4 Material properties

2.4.1 Reinforcement

The tested yield strength of main bars (DB12) is 474 MPa and the ultimate tensile strength is 782 MPa. The tested yield strength of stirrups (RB6) is 380 MPa and the ultimate tensile strength is 457 MPa. The tested yield strength of skeleton steel (RB9) is 346 MPa and the ultimate tensile strength is 427 MPa.

2.4.2 Concrete

The specimens were cast by ready mixed concrete. Before they were cast, the slump was taken and found to be between 80-100 mm. After finishing concrete placement, they were left 24 hours before curing by wet burlaps as shown in Figure 4 (a). The tested compressive strength of standard cylindrical specimen at 28 days is 41 MPa.

2.4.3 Ferrocement

The plastering mortar was mixed with the water:cement:sand ratio of 1:2:4 by weight. The target compressive strength at 7 days is 50 MPa. After plastering mortar to the lap splice area, it was left 24 hours and then covered by wet burlaps as shown in Figure 4 (b).

a) After casting

b) After application of ferrocement

Figure 4 Curing of specimen

2.5 Instrumentations

2.5.1 Transducer

The deflection of specimens was measured by 5 transducers as shown in Figure 5. The transducers at position 1 and 2 were to measure support vertical movement. The transducers at position 3 and 4 were to measure vertical deflection at 1/4 span length. The midspan deflection was measured by transducer 5.

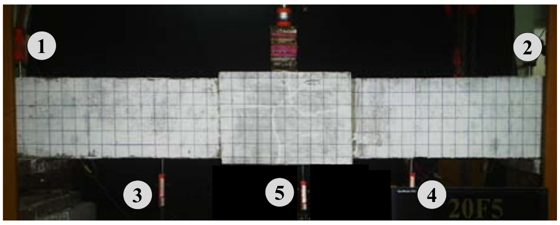


Figure 5 Position of transducers

2.5.2 Strain gages

The strain distributions along lap splice length were measured by strain gages. Figure 6 shows the strain gages attached on both bottom bars at the same distance. The distance of strain gage positions start from the midspan (the starting point of lap splice) as shown in Table 2.

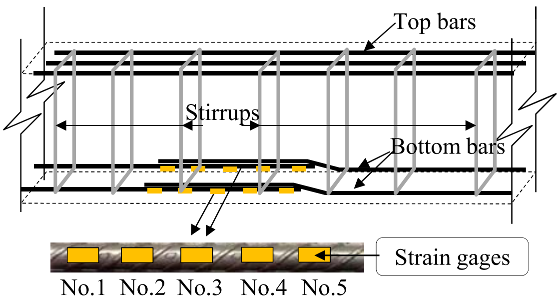


Figure 6 Strain gages along lap splice length

Table 2 Strain gage positions on lap splice length

<table>
<tr><th rowspan="2">Series</th><th rowspan="2">List name</th><th colspan="5">Strain gage positions (mm)</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td rowspan="4">25db</td><td>25F0</td><td>30</td><td>120</td><td>180</td><td>250</td><td>-</td></tr>
<tr><td>25FP</td><td>30</td><td>120</td><td>180</td><td>250</td><td>-</td></tr>
<tr><td>25F5</td><td>30</td><td>70</td><td>120</td><td>180</td><td>250</td></tr>
<tr><td>25F10</td><td>30</td><td>70</td><td>120</td><td>180</td><td>250</td></tr>
<tr><td rowspan="4">20db</td><td>20F0</td><td>20</td><td>90</td><td>180</td><td>220</td><td>-</td></tr>
<tr><td>20FP</td><td>20</td><td>90</td><td>180</td><td>220</td><td>-</td></tr>
<tr><td>20F5</td><td>20</td><td>80</td><td>120</td><td>180</td><td>220</td></tr>
<tr><td>20F10</td><td>20</td><td>80</td><td>120</td><td>180</td><td>220</td></tr>
</table>

2.6 Applied load

The point load is statically applied at midspan through hydraulic actuator. The load cell with 100 kN capacity is used to measure the load. The load is applied incrementally at 2.5 kN. At each load increment, the deflection and the cracks were recorded.

3. Experimental results

3.1 Load-Deflection

The deflection (Δ) is obtained by subtracting measured support deflections (position 1 and 2) from measured mid-span deflection (position 5) as shown in Equation (1).

$$\Delta = (5) - \frac{(1) + (2)}{2} \qquad (1)$$

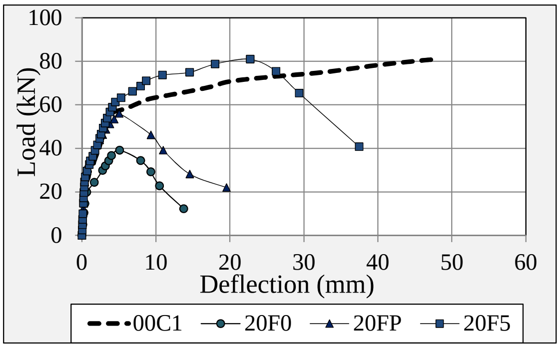


Figure 7 Load versus deflection of series 20db and 00C1

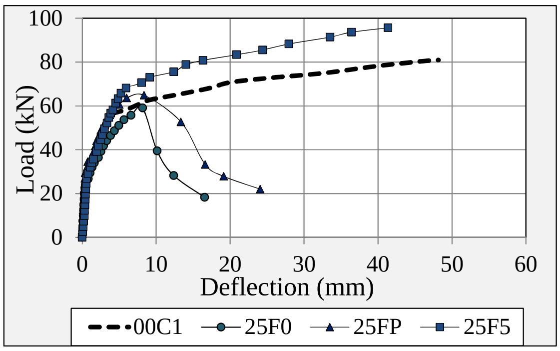


Figure 8 Load versus deflection of series 25db and 00C1

The test results are shown in Figures 7 and 8. In each figure, the control specimen 00C1 is shown as a dash line. From Figure 7, when comparing specimen 20F0 with 00C1, it can be seen that specimen 20F0 can resist the maximum load of 40 kN at deflection of 5.1 mm. After that, the graph dropped suddenly. As for specimen 20FP, the maximum load was 56 kN at 5.10 mm deflection. The load dropped suddenly after reaching the peak load. It can be seen that the use of ferrocement without skeleton steel could not develop the yield strength of steel bar. As for specimen 20F5, the maximum load is 80.93 kN at 22.75 mm deflection. It can be seen that this specimen can develop yield strength of steel bar. The strengthening by ferrocement jacket with skeleton steel is shown to increase both load and deformation capacity. The strength increase is higher than that of 00C1.

Figure 8 shows the comparison between specimens in series 25db with the lap length of 300 mm. In this figure, specimen 25F0 without any retrofit can resist the maximum load of 59.06 kN at 6.02 mm deflection. The load dropped suddenly after reaching the peak. The tendency was similar to series 20db. For retrofitted specimens 25FP and 25F5, both of them could reach yield load, but the strength of specimen 25FP dropped suddenly when reaching the peak. The highest load of specimen 25FP was 64.89 kN. However, specimen 25F5 could reach the highest load up to 95.65 kN and could deform as much as 41.4 mm. When compared with specimen 25F0, it can be seen that strengthening by ferrocement jacket with skeleton steel is very effective to increase both strength and deformation capacity of the specimen.

3.2 Cracks pattern

The crack patterns were recorded during the tests. The photos of the specimens after finishing the test are shown in Figure 9-13. Figure 9 shows the crack pattern of specimen 00C1. Most vertical cracks occur in the midspan region of the beam. On the other hand, the failure of specimen 20F0 without retrofitting showed less vertical cracks than observed in 00C1 (Figure 10). A large horizontal crack along the lap splice could be clearly observed. It was observed that once this horizontal crack formed, the load dropped suddenly. This horizontal crack is thought to be caused by bond splitting failure.

Figure 9 Crack pattern of specimen 00C1 at failure

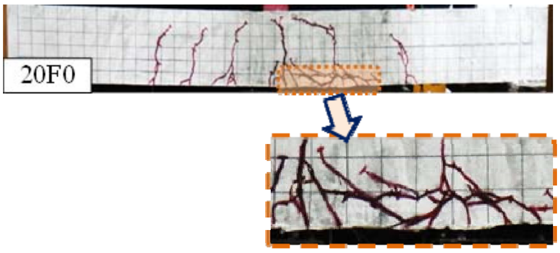


Figure 10 Crack pattern of specimen 20F0 at failure

The crack pattern of specimens 25F5 retrofitted by ferrocement jacket with skeleton steels is shown in Figure 11. When ferrocement jacket is removed from the main beam, the cracks are revealed as shown in Figure 12-13. Figure 12 shows the crack pattern of specimen retrofitted by ferrocement jacket without skeleton steels. A large horizontal splitting crack can be clearly observed. However, when skeleton steels are added to ferrocement jacket, it can be seen that the crack pattern at failure is similar to specimen 00C1 with continuous bars (Figure 9). From this observation, it can be clearly seen that ferrocement jacket with skeleton steel are effective to retrofit the lap splice in reinforced concrete beam.

Figure 11 Crack pattern of specimens retrofitted by ferrocement jacket

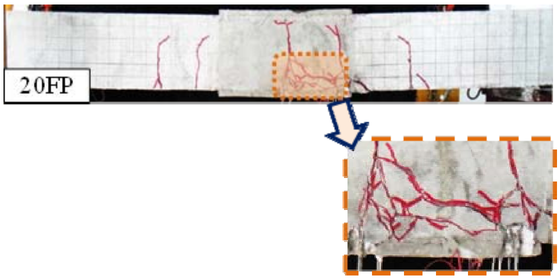


Figure 12 Crack pattern of specimens retrofitted by ferrocement jacket without skeleton steel (observed on main beam)

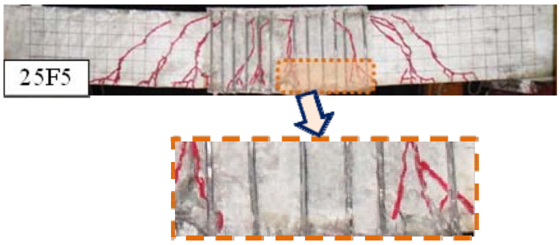


Figure 13 Crack pattern of specimen retrofitted by ferrocement jacket with skeleton steel (observed on main beams)

3.3 Strain distribution

Figure 14 and 15 show strain distributions of series 20db and 25db respectively. Trend lines are drawn from scattered data points at critical stage or ultimate stage. In Figure 14, the continuous lines represent strain distribution of 20F0, it can be seen that trend line of strain at critical stage, which is equal to 2,335 micron, is less than other one. It cannot develop strain higher than 3,000 micron which is strain at yield point. Trend line of 20FP can slightly increase strain from 20F0 but the strain is still less than strain at yield point. Addition of skeleton steel (dash line) in series 20db can develop strain up to 3,313 micron, which is higher than yield strain (3,000 micron).

The tendency of strain distributions of series 25db is similar to series 20db as shown in Figure 15. In Series 25db, the lap splice length of 25db is 300 mm which is more than that in series 20db, but the un-strengthened specimen still cannot develop the strain more than the strain at yield point. However, for strengthened specimens, i.e., specimens 25FP and 25F5, the strains can be higher than 3,000 micron in both specimens. The results of strain distributions confirm that strengthening with skeleton steel addition can change lap splice strength from pre-yield to post-yield range. Based on these test results, the effectiveness of ferrocement to strengthen short lap splice is verified.

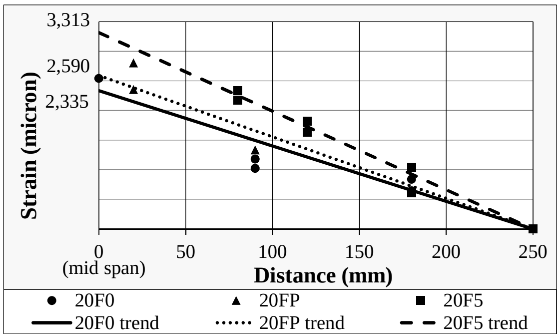


Figure 14 Strain distribution along lap splice length of series 20db

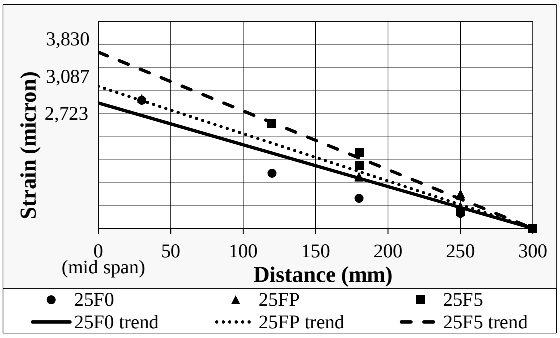


Figure 15 Strain distribution along lap splice length of series 25db

4. Conclusions

From the experimental study conducted in this research, the effectiveness of ferrocement jacket without the preparing-surface specimen for strengthening short lap splice is verified. Two experimental series are performed, that is 20db (splice length = 250 mm) and 25 db series (splice length = 300 mm). A total of 7 specimens have been tested under static load applied at the midspan of the beam. From the test results, the following conclusions can be drawn.

The specimens with lap splice length of 20 and 25 times bar diameter cannot develop yield strength of steel bars. The failure is brittle and caused by the horizontal splitting crack occurring along the lap splice zone.

Retrofitting specimens by ferrocement jacket without skeleton steel can slightly increase the strength of the specimens due to the increase of the effective depth, but does not enhance the deformation capacity.

Retrofitting specimens by ferrocement jacket with skeleton steel can substantially increase both the strength and deformation capacity of the specimens. This retrofit method is also effective to develop the yield strength of steel bars.

Author's guideline for strengthening using ferrocement, the surface of existing RC beams should be roughened before strengthening to more effectiveness of capacity load of composite structure. The skeleton steel can be used with diameter of 6 mm but not more than 10 mm.

5. Acknowledgement

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