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Performance of High Strength Concrete Specimens with Square Section Using Steel Strapping Tensioning Technique

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ABSTRACT

High strength concrete (HSC) has lower ductility, but higher in strength compared to normal strength concretes. The strength and ductility of HSC can be improved by applying external confinement, such as steel strapping tensioning technique (SSTT). However, SSTT was literately reported effective in confining circular specimens, but the effectiveness of SSTT on square cross section specimens are yet well investigated. This study focuses on HSC square cross section specimens with different corner ratio, which were right angle and rounded corner. In addition, the effect of different number of layer of steel straps confining around the specimens under optimum lateral pre-tensioning stress also been investigated. The number of layers was fixed to two layers and four layers. Fifteen HSC specimens with dimension of 88 mm x 88 mm x 200 mm, which consist of three unconfined specimens, six right angle specimens, and six rounded corner specimens were prepared and tested monotonically to failure. The experimental results show that the strength and ductility of HSC improved significantly by using rounded corner confined specimens and higher number of layer of confinements. This is due to more uniform confining pressure was exerted on entire surface of rounded corner confined specimens. The strength and ductility of the specimens can be improved up to 53.7% and 207.5% respectively

Keywords: Ductility and strength enhancement, high strength concrete (HSC), lateral pre-tensioning stress, rounded corner square cross section, steel strapping tensioning technique (SSTT)

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INTRODUCTION

Concrete with uniaxial compressive strength greater than what is ordinarily obtained in a region is generally used to definite as HSC (Catherine et al., 1998). But, the concrete with very high strength had lower ductility. This suggested concrete will have immediate failure when it reaches the maximum resistance to the compressive strength which is applied (Maghsoudi & Shari, 2009). According to Hadi (2008), the brittleness problem is also considered as a challenge of using HSC, because high strength concrete is low in brittleness and can easily break when subjected to excessive uniaxial load. According to Galeota and Giammatteo (1992), the strength and ductility of HSC can be improved by applying confinement. Many confinement methods were used to increase the strength and ductility of HSC, such as concrete jacket, steel jacket, fibre reinforced concrete (FRC), steel strapping tensioning technique, etc. However, the usage of existing confinement methods are affected by its high costs, difficult practice, and need to interrupt use of structure during repairing work (Moghddam et al., 2009). Hence, SSTT was introduced because of its very low-cost method in replacing existing confinement methods (Moghddam et al., 2009). This technique utilizes lateral pre-tensioning stress to confine the concrete columns and was experimentally proved to enhance the compressive strength and ductility of concrete column, especially for low lateral dilates HSC.

Literately, external confinement applied on rectangular or square shaped concrete will be less effective compared to circular sections under the same degree due to the better uniform distribution capability of lateral confining pressure around circular concretes compared to square concretes (Sharma et al., 2005). To date, the application of this technique with different corner ratio specimens confined with optimum lateral pre-tensioning stress remains to be investigated. In this paper, the square cross section right angle and rounded corner HSC confined with two layers and four layers of steel straps under optimum lateral pre-tensioning stress are presented and investigated.

MATERIALS AND METHODS

Specimen Preparation and Materials

Fifteen square specimens with dimension of 88 mm x 88 mm x 200 mm were prepared, which consist of nine right angle square shaped specimens and six square specimens with rounded corner. All the specimens were cast according to the mixture proportions shown in Table 1. After 24 hours, all specimens were removed from formworks and undergone wet curing in water for 28 days. Then, all the specimens were externally confined by steel straps by using pneumatic tensioner with the optimum lateral pre-tensioning stress obtained from previous batch of study. The prescribed number of layer and the lateral pre-tensioning stress confined to all specimens were shown in Table 2. The spacing of steel straps were fixed at 10 mm along the centre of column and 5 mm in the end regions to avoid premature failure of HSC. The detail of confined specimens is shown in Figure 1.

Experimental Testing

The monotonic compressive test was carried out at Geotechnical Laboratory of Faculty of Civil Engineering, University Teknologi Malaysia. The monotonic compressive test was carried out by using TINIUS OLSEN super "L" Universal Testing Machine, with a capacity of 3 MN and a constant rate of 0.4 mm/min as shown in Figure 2. All the specimens were tested until failure. Three linear variable differential transducers (LVDTs) were located at the top part of load cell to determine the longitudinal axial deformation of the specimens, while two omega strain gauges were located at the centre of specimens in adjacent direction. The transverse deformations of the specimens were determined using two LVDTs that located at the centre of the specimens. The LVDTs with gage length of 25 mm were used and attached at the shaft of the machine. The transverse deformations for concrete and steel strap were determined using two strain gauges that installed at the centre part of specimens in adjacent side. The strain gauges and load cell were connected to the data logger and computer to measure the value of strain and applied load respectively for all specimens. The arrangement of all LVDTs and tool used on all specimens during testing were shown in Figure 3. Any cracking pattern, buckling, deformation, fail condition, etc, were recorded during tests for all specimens.

Table 1
Concrete mixture proportion for 60 Mpa concretes

Materials	Quantity
Ordinary Portland cement (OPC)	550 kg
Fine aggregates	885 kg
Coarse aggregates	957 kg
Water	190 kg
Super-plasticizer (SP) - Glenium ACE388 (RM)	0.75 % of 100 kg cement

Table 2
Number of steel strap layer and lateral pre-tensioning stress applied

Specimen	No. of specimens	Number of steel strap layer	Lateral pre-tensioning stress applied
Control	3	0	0
2PT – 5B	3	2	5 bars
2PT – 5B (CR)	3	2	5 bars
4PT – 4B	3	4	4 bars
4PT - 4B (CR)	3	4	4 bars

*CR = Corner Radius

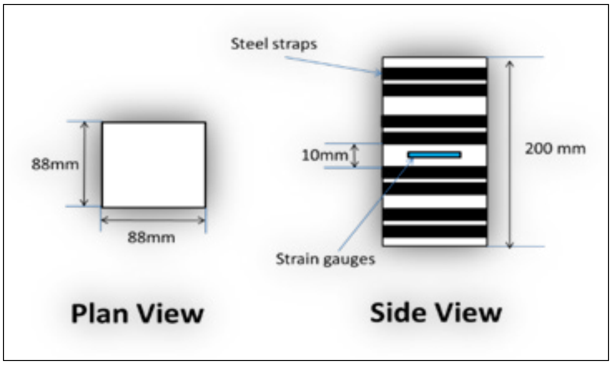
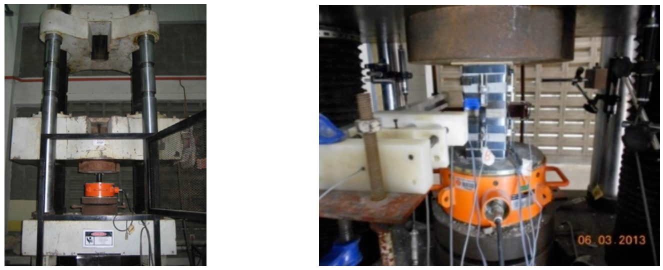


Figure 1. Arrangement of steel straps on specimens



(a) (b)

Figure 2. The Experimental Tools Used During Testing: (a) TINIUS OLSEN Super "L" Universal Testing Machine; and (b) Diagram for equipment (Lvdts)

RESULTS AND DISCUSSION

Failure mode

Figure 3(a) to (e) show the failure mode of the representative specimens for each case. For unconfined specimens, C60-C-sqr-02 as shown in Figure 4(a) was used and discussed in this section. All the unconfined specimens were undergone serious failure or crushing, and undergone explosion with explosive sound after reaching the peak compressive strength during testing. Unconfined specimens collapsed in deep diagonal shear mode, so this type of failure was called diagonal failure. The average maximum compressive strength can be achieved by unconfined specimens were 54.3266 MPa. While, all confined specimens were shown in the Figure 4(b) to (e). Confined specimens were undergone diagonal shear crack and minor crush compared with unconfined specimens. During experimental testing, the specimens fail gradually without explosion when approaching maximum compressive strength of specimens. This phenomenon occurred due to the function of lateral pre-tensioning steel straps in preventing confined specimens to collapse steeply and behave more ductile compared with unconfined specimens. The maximum compressive strength can be achieved by right angle specimens confined with two layers and four layers of steel straps which were 60.6495 MPa and 61.4243 MPa, and which significantly improved by 11.8% and 13.1% compared with unconfined specimens respectively. On the other hand, the maximum compressive strength can be achieved by rounded corner specimens confined with two layers and four layers of steel straps were 77.4897 MPa and 94.3944 MPa, which significantly improved by 42.6% and 78.8% compared to unconfined specimens respectively.

Experimental Results and Discussion

Table 3 shows the average experimental results obtained for all tested specimens, which consists of unconfined specimens and confined specimens with different layer of steel strap and lateral pre-tensioning stress. From the table, the f_{co} and ε_{co} are the peak compressive strength and peak compressive strain for unconfined specimens respectively. While, fcc and Ɛcc are the strength and strain at the point of maximum compressive strength for confined specimens (specimens confined by two layers and four layers of steel strap with optimum lateral pre-tensioning stress, which is five bars for two layer confined specimen and four bars for four layer confined specimen). Lastly, ε_{85} and ε_{50} are the strain at 85% and 50% of maximum compressive strength after achieve the full peak compressive strength of specimens. Figure 4 and Table 3 clearly shows that the average maximum compressive strength achieved by all confined specimens was higher than the average maximum compressive strength for unconfined specimens. The average strength enhancement achieved by all confined specimens were 11.8%, 13.1%, 42.6%, and 73.8% for 2L5B, 4L4B, 2l5B (CR), and 4L4B (CR) respectively. It can be concluded that the average maximum strength of specimens able to be improved up to 73% by using corner radius specimens, because rounded corner specimens can help in increasing of confinement effectiveness of steel straps on confined specimens.

(a) (b) (c) (d) (e)

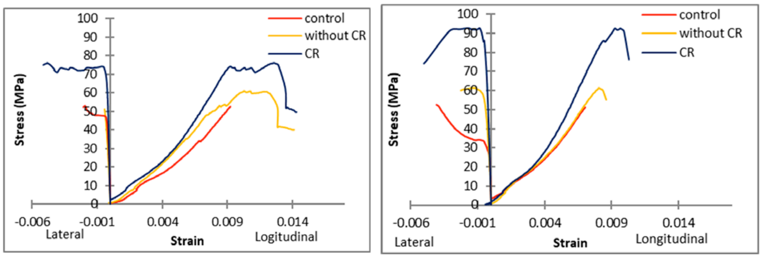
Figure 3. The cracking pattern of: (a) unconfined specimen; (b) two layers steel straps with four Bars confined specimen; (c) four layers steel straps with four Bars confined specimen; (d) rounded corner two layers steel straps with four Bars confined specimen; and (e) rounded corner four layers steel straps with four Bars confined specimen

Table 3
Average experimental results for all specimen

Specimen	f_{co}	ε_{co}	f_{cc}	ε_{cc}	ε_{85}	ε_{50}	f_{cc}/f_{co}	$\varepsilon_{cc}/\varepsilon_{co}$	$\varepsilon_{85}/\varepsilon_{cc}$	$\varepsilon_{50}/\varepsilon_{cc}$
Control	54.3266	0.0081	-	-	-	-	-	-	-	-
2L5B	-	-	60.6495	0.0110	0.0127	0.0280	1.1184	1.3580	1.1604	2.5477
4L4B	-	-	61.4243	0.0081	0.0093	0.0134	1.1306	1.0000	1.1481	1.6543
2L5B (CR)	-	-	77.4897	0.0128	0.0346	0.0134	1.4264	1.5802	1.0664	2.6926
4L4B (CR)	-	-	94.3944	0.0089	0.0348	0.0412	1.7375	1.1481	1.1198	3.9401

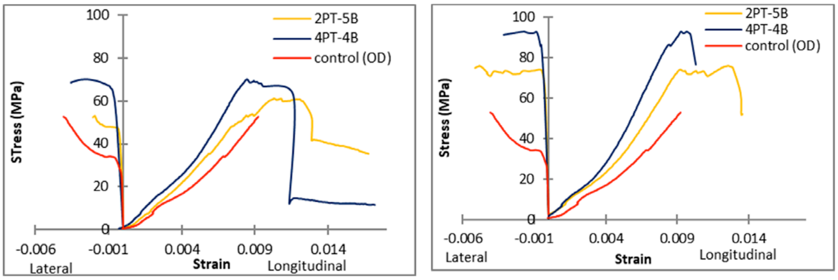
Besides, Figure 4 and Table 3 also show that the rounded corner specimens able to achieve higher average compressive strength compared to right angle specimens and unconfined specimens under similar number of steel straps. For two layers steel straps and four layers confined specimens, there were up to 27.8% and 53.7% higher average compressive strength achieved by rounded corner specimens compared to right angle specimens respectively. While, Figure 5 and Table 3 show that the specimens confined with four layers steel straps able to achieve higher average compressive strength compared to two layers steel straps confined specimens under similar shape section. Average compressive strength enhancement between two layers and four layers confined specimens for both right angle and rounded corner confined specimens were 1.3% and 21.8% respectively. In short, the compressive strength of confined specimens is directly proportional to the number of steel straps confined on the specimens. Secondly, rounded corner confined specimens able to achieve higher compressive strength compared to right angle confined specimens under same level of pre-tensioning stress and layers of steel straps used, because more uniform confining pressure was exerted on entire surface of rounded corner confined specimens that more effective or fully confined. From Figure 6 and Figure 7, it can be clearly noticed that the mobilization of steel straps started immediately when the tests started. It shows that the optimum lateral pre-tensioning stress used in this study with different layers of steel strap can be effectively confined the low lateral dilates HSC, even with different corner ratio of square shape including right angle.

The plasticity ratio of confined specimens, defined as the ratio of two strains, which are ε_{85} and εcc (e.g. $\varepsilon_{85}/\varepsilon_{cc} > 1$). Based on the Table 3, the average plasticity ratio for two layers and four layers steel straps confined right angle specimens are 1.1604 and 1.1481 respectively. While, the average plasticity ratio for two layers and four layers steel straps confined corner radius specimens are 1.0664 and 1.1198 respectively. This indicates the average plasticity ratio can be improved up to 16% and 12% for right angle and rounded corner confined specimens respectively. The ductility ratio of confined specimens, defined as the ratio of two strains, which are ε_{50} and ε_{cc} (e.g. $\varepsilon_{50}/\varepsilon_{cc} > 1$). Based on Table 3, it can be clearly noticed that the average ductility for two layers and four layers steel straps confined right angle specimens were increased by 154.8% and 65.4% respectively. While, the average ductility for two layers and four layers steel straps confined rounded corner specimens were increased by 169.3% and 294% respectively, which were almost 3 times higher than average ductility of unconfined specimens. For comparison between two layers and four layers confined specimens, depletion in average ductility up to 109% happened on right angle specimens, but the average ductility for rounded corner confined specimens was improved up to 207.5%. For comparison between right angle and rounded corner confined specimens, depletion in average ductility up to 109% happened on two layers confined specimens, but the average ductility for four layers confined specimens was improved 207.5%. In short, SSTT can effectively improve the strength and ductility of four layers confined specimens and rounded corner confined specimens.



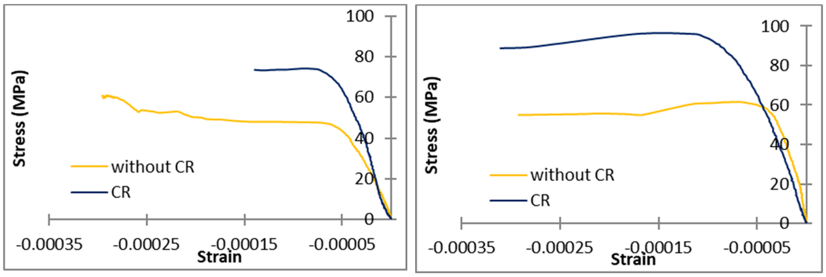
(a) (b)

Figure 4. Stress-strain curves of unconfined concrete, concretes without rounded corner, and concretes with rounded corner confined with: (a) two layers of steel straps and five bars of lateral pre-tensioning stress; and (b) Four layers of steel straps and four bars of lateral pre-tensioning stress



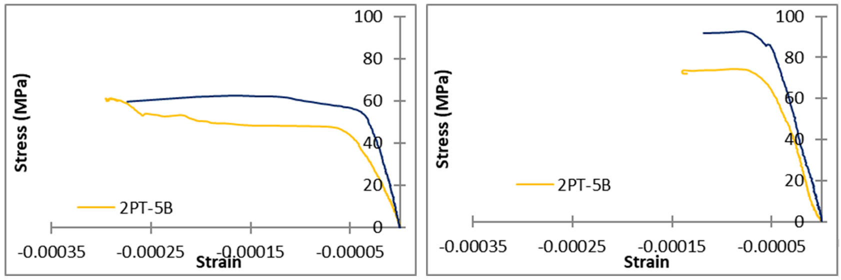
(a) (b)

Figure 5. Stress-strain curves for specimens confined with two and four layers of steel strap: (a) Unconfined concrete and confined concrete without rounded corner; and (b) Unconfined concrete and confined concrete with rounded corner



(a) (b)

Figure 6. Stress-strain curves of unconfined concrete, concretes without rounded corner, and concretes with rounded corner confined with: (a) two layers of steel straps and five bars of lateral pre-tensioning stress; and (b) Four layers of steel straps and four bars of lateral pre-tensioning stress



(a) (b)

Figure 7. Stress-strain curves for specimens confined with two and four layers of steel strap: (a) Unconfined concrete and confined concrete without rounded corner; and (b) Unconfined concrete and confined concrete with rounded corner

CONCLUSION

This study has been focused on performance of square HSC specimens using SSTT. All the experimental results obtained were analysed and presented together with the discussion on the experimental results and failure mode for all specimens. Hence, the following conclusion may be drawn from the results and observation obtained during experiments: The SSTT confined HSC able to achieve higher compressive strength and ductility compared to unconfined HSC. The average strength enhancement achieved by all confined specimens were 11.8%, 13.1%, 42.6%, and 73.8% for 2L5B, 4L4B, 2l5B (CR), and 4L4B (CR) respectively. While, the average ductility enhancement achieved by all confined specimens were 154.8%, 65.4%, 169.3%, and 294% for 2L5B, 4L4B, 2l5B (CR), and 4L4B (CR) respectively. Four layers steel straps confined specimens able to achieve higher strength and ductility compared to two layers steel straps confined specimens. For right angle specimens, the average strength enhancement between two layers and four layers steel straps confined specimens was 1.3%, but the results show depletion of 109% in ductility. While, for rounded corner specimens, the average strength and ductility for confined specimens were increased up to 21.8% and 207.5% respectively. The specimens with rounded corner able to achieve higher strength and ductility compared to right angle specimens. For two layers confined specimens, the average strength enhancement between right angle and rounded corner confined specimens was 27.8%, but the results show depletion of 109% in ductility. While, for four layers confined specimens, the average strength and ductility for confined specimens were increased up to 53.7% and 207.5% respectively.

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REFERENCES

Catherine, F. U., Mokhtarzadeh, A., Ahlborn, T., & Leon, R. (1998). High-strength concrete applications to prestressed bridge girders, *Construction and Building Materials, 12*(2-3), 105-113.

Galeota, D., & Giammatteo, M. M. (1992). Strength and ductility of confined high strength concrete. *Earthquake Engineering tenth world conference @ 1992balkemaRotterdam*, ISBN90 5410 060 5.

Hadi, M. N. S. (2008). Bond of high strength concrete with high strength reinforcing steel. *The Open Civil Engineering Journal, 2*, 143-147.

Maghsoudi, A. A., & Sharifi, Y. (2009). Ductility of high strength concrete heavily steel reinforced members. *Journal of Scientia Iranica, 16*(4), 297-307.

Moghddam, H., Mohebbi, S., & Samadi, M. (2009). Experimental and analytical investigation of concrete confined by external pre-stressed strip. C*oncrete Repair, Rehabilitation and Retrofitting 2-Alexander et al. (eds)*, ISBN 978-0415-46850-3.

Sharma, U. K., & Bhargava, P. (2005). Behavior of confined high strength concrete columns under axial compression. *Journal of Advanced Concrete Technology, 3*(2), 267-281.