Experimental squash load of concrete-filled thin welded cold formed steel stubs with different welding fillets location

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ملخص

في هذا العمل، نعرض نتائج تجارب أجريت على أعمدة قصيرة و مستطيلة مصنوعة من صفائح فولاذية ملحومة بعد طيها على شكل U مشكلة مستطيلات أبعادها هي : 2x70x100 مم لعناصر الرئيسية التي تمت دراستها هي : الطول (50 – 500 مم) الأثر الملموس لمكان لحم. أجريت الاختبارات بعد 28 يوما من تاريخ الصب الخرسانة التي تم صنعها من خبث الفرن عوض الحصى العادية على 28 عينت 14 مليئة و14 فارغة وضعت كلها تحت ضغط محوري يصل إلى الفشل بواسطة جهاز ضغط. أكدت نتائج التجارب أن العينات الفارغة تأثرت بشكل كبير وبسرعة خاصة مع زيادة في الطول . بينما هناك مقاومة ملحوظة للعينات المملوءة تصل إلى الضعف نتيجة الأثر الايجابي لخرسانة المستعملة في ملء العينات. يبدو أن موقع لحم الشرائح تأثيره طفيف على قوة التحميل.

الكلمات المفتاحية: *الهياكل المركبة*؛ الأعمدة الفولاذية المملوءة بالخرسانة؛ *جفاء الصلب المبلور*؛ جهد الانكسار.

Résumé

Le présent travail est une contribution expérimentale sur la capacité portante des tubes minces en acier laminés à froid, soudés et remplis de béton à base de laitier sous chargement axial. La fabrication de la section des tubes a été réalisée en pliant une tôle de 2 mm en forme de U et soudée sur le petit ou grand coté pour former des tubes de section rectangulaire et de dimensions: $100x70x2mm^3$. Les principaux paramètres étudiés sont: La hauteur du tube variable de 50 à 500 mm, le matériau de remplissage et l'effet de la localisation des soudures sur la capacité portante des tubes vides et remplis. Les essais ont été effectués 28 jours après la date du coulage du béton, Les éprouvettes vides et remplies sont soumises à la compression jusqu'à la rupture. Un total de 28 éprouvettes ont été testées, 14 vides et 14 remplies de béton fabriqué à la base de laitier cristallisé comme agrégat en substitution des agrégats conventionnels. Les résultats obtenus montrent que les tubes vides ont souffert du phénomène de flambement local par cloquage des parois vers l'extérieur et l'intérieur, ce qui explique les capacités portantes faibles obtenues avec l'augmentation de la hauteur des tubes. Les tubes remplis ont une capacité portante plus importante jusqu' à 2 fois celle des tubes vides. Un résultat qui explique bien l'action composée de l'acier et du béton. La position du cordon de soudure influe uniquement sur la capacité portante des tubes vides. Il ya une augmentation de 13% de celle-ci lorsque la soudure se trouve au milieu du grand coté.

Mots clés : *structures mixtes; tubes en acier remplis de béton; laitiers cristallisé; charge de rupture*

Abstract

In the present work, results of tests conducted on thin welded rectangular steel-concrete stubs are presented. The stub section was made from two U shaped cold formed steel plates welded to form box whose dimensions were: 100x70x2mm. The main parameters studied were: stub height (50-500mm), effect of the concrete infill and the weld fillet location. The tests were carried out 28 days after the date of casting the concrete infill under axial compression up to failure. A total of 28 stubs were tested, 14 were empty and 14 filled with concrete made with crushed crystallized slag aggregate. The object of the study was to investigate the failure load of composite sections and the use of crushed slag instead of conventional aggregate. From test results it was confirmed that the length of stubs had a drastic effect on the failure load and resulted from local buckling. It appeared that the location of weld fillets had only a slight effect on the failure load for empty steel stubs and was insignificant for composite stubs.

Key words: *composite structures; concrete filled steel stubs; crystallised slag; failure load.*

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1. INTRODUCTION

Composite columns have been used widely as they speed up construction by eliminating formwork and have high load carrying capacity1 and the use of thin steel wall thickness is more economic. The major difficulty encountered is however the local buckling of the steel wall especially in the case of stocky columns2-3. Very few experiments have been performed on cold formed welded steel sections filled with concrete or recycled materials4-5 such as slag stone concrete (SSC). The latter has been tested under direct compression and was used as a filling material to overcome the undesired effects of imperfections in built up cold formed sections2-3. The gain in strength was found to reach a value of up to 2 and decreased linearly with the tube height6-7. Results from an experimental program8 on the behaviour of high strength concrete-filled steel hollow structural section (HSS) columns were presented for three types of concrete filling. A comparison was made of the fire-resistance performance of HSS columns filled with normal strength concrete, high strength concrete, and steel fibre-reinforced high strength concrete. The various factors that influence the structural behaviour of high strength concrete-filled HSS columns under fire conditions were also discussed. It was demonstrated that, in many cases, addition of steel fibres into high strength concrete improves the fire resistance and offers an economical solution for fire-safe construction. A theoretical study of the local and post-local buckling of thin-walled circular steel tubes that contain a rigid infill was presented9. This generic approach was calibrated against test data, and a cross-section slenderness limit was proposed that delineates between a fully effective cross-section and a slender cross section. A simple prescriptive equation was proposed for the buckling strength of the steel cross section that is consistent with many design codes, and illustrates that the presence of an infill may enhance the cross-sectional strength, not only by the added strength of the infill itself, but by delaying the buckling of the steel tube. An experimental and theoretical10 treatment of coupled local and global buckling of concrete filled steel columns was presented. The work was concluded with comparisons of design recommendations for the strength evaluation of slender composite columns with thin-walled steel sections. Results of tests6 conducted on 27 concrete-filled steel tubular columns were reported. The test parameters were the column slenderness, the load eccentricity covering axially and eccentrically loaded columns with single or double curvature bending and the compressive strength of the concrete core. The test results demonstrate the influence of these parameters on the strength and behaviour of concrete-filled steel tubular columns. A comparison of experimental failure loads with the predicted failure loads in accordance with the method described in Eurocode 4 Part 1.1 showed good agreement for axially and eccentrically loaded columns with single curvature bending whereas for columns with double curvature bending the Eurocode loads were higher and on the unsafe side. More tests were reported to be needed for the case of double curvature bending. Thirty-six specimens11, including 30 stiffened stub columns and six unstiffened ones, were tested to investigate the improvement of ductile behaviour of stiffened composite stub columns. The parameters investigated were stiffener height, stiffener number on each tube face, using saw-shaped stiffeners, welding binding or anchor bars on stiffeners, and adding steel fibres to concrete. It has been found that adding steel fibres to concrete is the most effective method in enhancing the ductility, while the construction cost and difficulty is not significantly increased. The behaviour of self-consolidating concrete (SCC) filled hollow structural steel (HSS) stub columns subjected to an axial load was investigated experimentally12. A total of 50 specimens were tested. A mathematical model was developed and a unified theory was described whereby a confinement factor was introduced to describe the composite action of the steel tube and the concrete infill. The predicted load versus deformation relationship was in good agreement with the test results. The theoretical model was used to investigate the influence of important parameters that determine the ultimate strength of the composite columns. The parametric and experimental studies provided information for the development of formulae for the calculation of the ultimate strength and the axial load versus axial strain curves of the composite columns. Comparisons were made with predicted stub column strengths using the existing codes. An experimental study on the behaviour of short concrete filled steel tubular columns (CFT) axially loaded in compression to failure was presented13. A total of 28 specimens (16 filled with concrete and 12 hollow) with different cross-sections were tested to investigate the load capacity. The length-to-diameter ratios of these columns were between 4 and 9. Parameters for the tests were tube shape and diameter-to-thickness ratio. Some of the concrete filled columns had internal bracing of #3 deformed bars. The test results are compared with the theoretical results and previous studies.

The results showed that the confinement effect on concrete does play a role in increasing the compressive strengths, in some cases by almost 60%. Based on the test results, an equation to estimate the ultimate axial compressive loading capacities was also proposed for square CFT columns. A series of tests14 were performed to consider the behaviour of short composite columns under axial compressive loading, two rectangular hollow steel sections (RHS) were used in these tests, (120 × 80 × 5 mm and 150 × 100 × 5 mm). The sections were filled with normal and lightweight concrete with natural pouzzolan as the lightweight aggregate. The main objectives of these tests were to clarify the performance of the lightweight aggregate-concrete filled steel specimens compared with those manufactured from normal concrete. The experimental investigations included tests on short steel and short composite columns. The experimental failure load was seen to be adversely affected when the height of the specimen was increased from 100 to 200mm. The results of this investigation showed that the contribution of lightweight aggregate concrete to the failure load was important. Thirty specimens, including 24 recycled aggregate concrete filled steel tubular (RACFST) columns and 6 normal concrete filled steel tubular (CFST) columns, were tested to investigate the influence of variations in the tube shape, (circular or square), concrete type, (normal and recycled aggregate concrete) and load eccentricity ratio, (0 to 0.53) on the performance of such composite columns. The test results showed that both types of filled columns failed due to overall buckling.

Comparisons were made with predicted ultimate strengths of RACFST columns using the existing codes. The theoretical model for normal CFST columns was used in this investigation for RACFST columns. The predicted load versus deformation relationships were in good agreement with test results. More test results are needed for thin cold formed steel tubes filled with non conventional concrete such as slag concrete to investigate the effect of weld fillet location on the failure load. The present work is a contribution to the understanding of the behaviour of SSC filled cold formed thin short steel tubes subjected to axial compression.

2. EXPERIMENTAL PROGRAM

To study the behaviour of SSC filled cold formed steel tubes 28 specimens were prepared. All had cross sectional dimensions of 100x70x2 mm. The main hollow steel tubes with stub heights from 50 to 500mm were tested under axial compression, 7 with the weld on the short side and 7 with the weld on the long side. The tests were repeated with tubes filled concrete mix as shown in Table 1.

Table 1. *Slag stone concrete mix properties.*

Cement content	350. kg/m^3
Water-cement ratio	.50
10mm crushed slag stones	1200. kg/m^3
Sand of crushed slag 2/5	600. kg/m^3
Slump	70. mm
Compressive strength at 28days	20. MPa
Ec	21. GPa

3. MATERIALS AND FABRICATION

The crushed stone and sand aggregate parameters studied were the stub height, infill concrete and weld fillet location (Fig.1). Steel coupons were prepared to investigate the tensile yield steel strength and concrete cylinders were tested under direct Compression after 28 days. 14 was replaced with 10mm crushed crystallized slag supplied by the iron manufacture ELHADJAR-ALGERIA. The use of such artificial stone instead of natural stone would contribute to environmental protection by the recycling of industrial waste. The 28 days compressive strength of SSC was 20 MPa

and the steel yield strength was 300.MPa with a Young's modulus of 205.GPa. During casting, concrete was vibrated externally with a shaking table for 2 to 3 minutes. All composite specimens were left in the curing room for a period of 28 days. Both, top and bottom faces of composite stubs were mechanically treated to remove surface irregularities and to ensure that both steel and concrete were loaded during the tests.

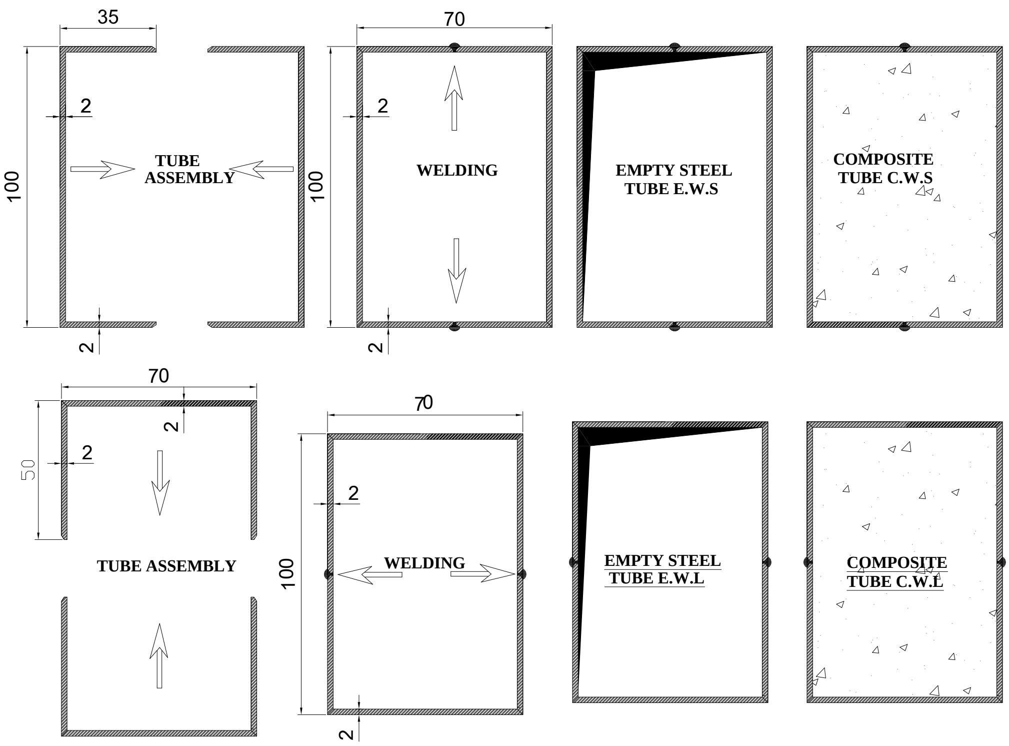

Figure 1. *Manufactured steel and composite cross section beams.*

4. Test rig and procedure

All specimens were tested in a 1000kN compression machine with an absolute accuracy of 0.5%. Special attention was given to verifying the correct position of the stubs before any loading. After the first load increment, a complete check of strains and load was carried out. Several loading and unloading cycles were performed at this stage. When the results were satisfactory, the loading proceeded to failure. Both top and bottom plates were hinged.

5. RESULTS OF STUB TESTS

Tables 2 and 3, show the results for hollow steel tubes and composite tubes respectively. The nomenclature used was as follows:

EWS hollow steel tubes welded in the middle of the short sides
EWL hollow steel tubes welded in the middle of the long sides
CWS composite steel/concrete tubes welded in the middle of the short side
CWL composite steel/concrete tubes welded in the middle of the long side

The main feature of failure of the empty thin wall steel tubes was the local buckling that took place in all samples with a small attenuation for longer tubes. Long and short sides buckled inwards and outwards respectively. The decrease in failure load with the stub height increase is shown in Fig.2. It was found that failure load increased when the weld fillet was located in the long sides. All test loads were far from the theoretical load carrying capacity which is calculated on the steel strength basis and neglecting the local buckling effect.

***Table 2**. Results for hollow stubs.*

Stub n°	HxBxt (mm)	Steel Area A_s (mm²)	Height L (mm)	Failure load Nsq(kN)	Test load (kN)
EWS50	102X68X2	664	50.	199.	160.
EWS100	102X68X2	664	100.	199.	159.
EWS150	102X68X2	664	150.	199.	156.
EWS200	102X68X2	664	200.	199.	148.
EWS300	103X68X2	668	295.	200.	146.
EWS400	104X68X2	672.	395.	201.	141.
EWS500	104X68X2	672.	490.	201.	140.
EWL50	98X75X2	676.	50.	202.	183.
EWL100	98X74X2	672.	100.	201.	180.
EWL150	98X74X2	672.	149.	201.	174.
EWL200	96X74X2	664.	198.	199.	169.
EWL300	94X72X2	648.	295.	194.	154.
EWL400	96X74X2	664.	395.	199.	150.
EWL500	98X75X2	676.	490.	203.	145.

The results of the composite group clearly show the benefit of composite steel-concrete stubs. The load ratio (composite/hollow) had an average value

of 1.80 for CWS samples and 1.75 for CWL samples, the ratio for the 50mm stub being much higher, a consequence of tri-axial stress state. It can also be seen from Table 3 and Figure 3 that the long side welded samples had a slightly higher load ratio than the short side weld samples. Both, large and small sides of the composite section buckled outwards significantly with attenuation for the longer samples. The carrying capacity of empty steel tubes with the weld fillet on the short sides varied from 160. to 140. kN and for tubes welded on the long side from 183 to 145 kN. The mean load carrying capacity increase when the weld is on the long sides of the section is about 13% for samples with height 50 to 200 mm and about 5% for samples with height of 300 to 500 mm, Fig. 2. For composite samples, test loads varied from 500 to 245 kN with weld fillet on the short sides and from 490 to 260 kN for weld fillet on the long sides. The mean load carrying capacity increase is approximately 5% when the weld fillet is on the long sides, Fig. 3. The mean test load ratio (filled / empty) for sections longer than 50mm was 1.80 for CWS and 1.75 for CWL. The 50mm sections had load ratios 3.12 and 2.67 respectively. This expresses well the advantage of filling cold formed and welded steel tubes with concrete. Knowing steel and composite test loads, concrete loads can be calculated by subtracting the test steel load from the composite test load. Hence, the average normal stress for the concrete can be approximately calculated[6]. Fig.4. Calculated mean failure loads for both empty and composite stubs were 200. and 270. kN respectively. Test results are shown in Fig.5, it can be seen that the experimental ultimate failure loads diverge from the theoretical value for empty steel stubs; this reflects the drastic effect of stub height on the axial load carrying capacity. Local buckling failure mode took place in all empty samples irrespective of the weld position. For the composite sections the experimental ultimate loads were greater than or close to the calculated composite failure load. This result was not reported in a previous work[6] where it was observed that composite test ultimate axial loads were lower than the theoretical failure load after 28 days curing. The difference between the experimental and theoretical values was found to decrease with composite samples where the concrete had been cured for 3 years. It is believed by the authors that the use of crushed slag stone and sand aggregate contributed in reaching the composite failure load level.

The in-fill concrete reduces local buckling as the steel walls are restrained from deforming outwards and the concrete core is contained by the steel envelop leading to a confined stress state which allows the concrete to withstand stresses greater than the 28 days cylinder strength. This explains the high values obtained for both composite samples CWS50 and CWL50. With the stub height increase, the confining effect of the steel is reduced but failure loads remained close to the theoretical.

Failure loads for both composite series CWS and CWL were close, confirming that the weld fillet location did not affect significantly the composite axial load carrying capacity. All composite samples failed by local buckling where the steel envelop deformed outwards. Photographs of some failed composite samples are shown in Fig. 7.

Table 3. *Results for composite stubs.*

Stub n°	HxBxt (mm)	Steel A_s (mm²)	Concrete A_c (mm²)	Height L (mm)	Squash loads Nsq(kN)	Test loads (kN)	Load Ratio Composite/ Hollow
CWS50	102X69X2	668	6370.	50.	273.	**500.**	**3.1**
CWS100	102X68X2	664	6272.	100.	270.	**290.**	**1.8**
CWS150	104X68X2	672	6400.	150.	274.	**285.**	**1.8**
CWS200	102X68X2	664	6272.	200.	270.	**270.**	**1.8**
CWS300	103X68X2	668	6336.	300.	272.	**265.**	**1.8**
CWS400	102X67X2	660	6174.	400.	268.	**250.**	**1.8**
CWS500	102X67X2	660	6174.	500.	268.	**245.**	**1.8**
CWL50	98X72X2	664	6392.	50.	272.	**490.**	**2.7**
CWL100	98X74X2	656.	6256.	100.	268.	**310.**	**1.7**
CWL150	98X73X2	668.	6486.	150.	274.	**300.**	**1.7**
CWL200	95X74X2	660.	6370.	200.	270.	**290.**	**1.7**
CWL300	95X74X2	660.	6370.	300.	270.	**270.**	**1.8**
CWL400	95X75X2	664.	6461	400.	273.	**265.**	**1.8**
CWL500	97X75X2	672.	6603.	500.	276.	**260.**	**1.8**

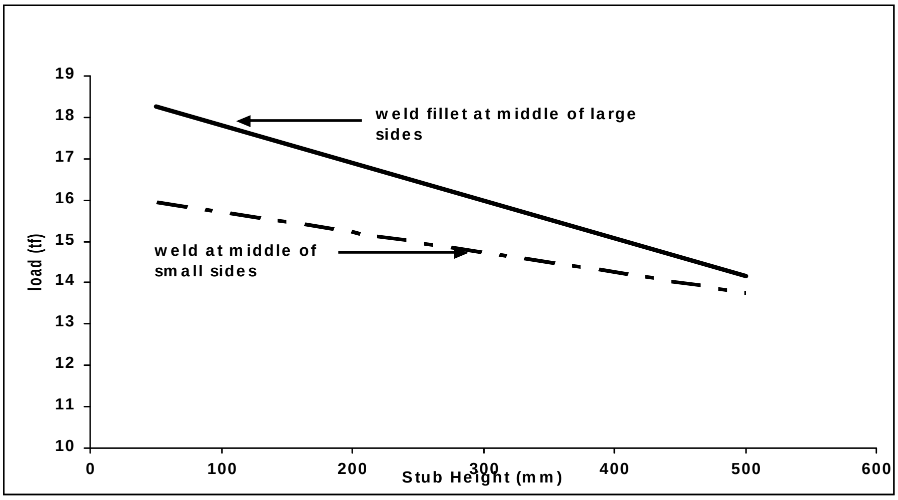

Figure 2*. Experimental failure loads for hollow steel tubes with different weld fillet locations.*

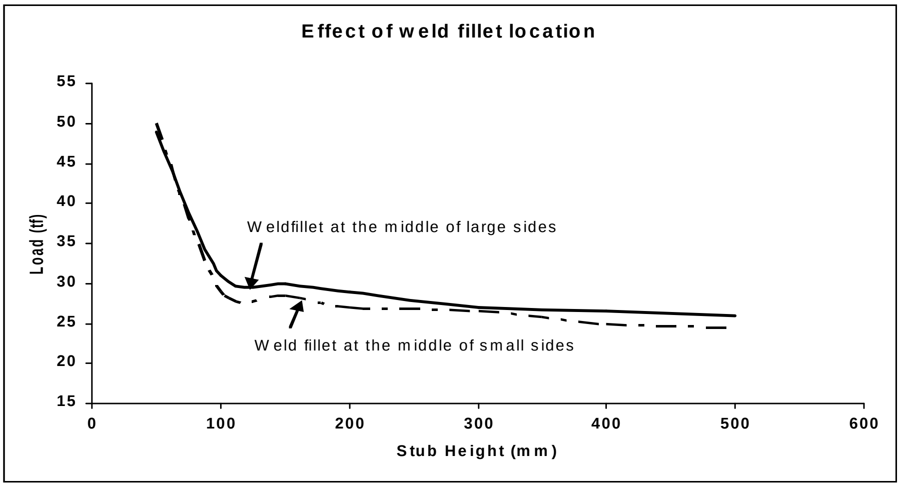

Figure 3. *Experimental failure loads for composite tubes with different weld fillet locations.*

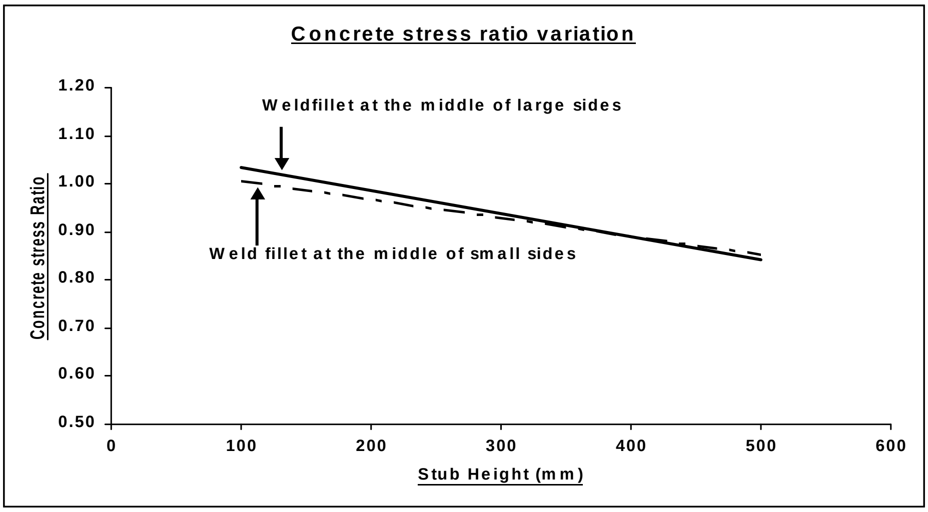

Figure 4. *Concrete mean stress ratio as a function of stub height.*

6. DISCUSSION

As no experimental evidence could be found on the effect of the welding location on the axial load carrying capacity it was decided to test empty and composite cold formed steel tubes with different weld fillet locations. The experimental results presented in Table 2 and Figure 2 for empty steel tubes show a slight increase of the axial load carrying capacity of 5 to 13% when the weld fillet is in the middle of the long sides of the steel cross section. The main feature of the failure of empty stubs is the local buckling that took place in all samples. Long and short sides deformed inwards and outwards respectively. Ultimate test loads were below the corresponding theoretical failure load, a consequence of the high H/t ratio which was 50 for all samples. Composite samples reached experimental loads beyond or close to the theoretical composite failure load. The infill concrete played a major role in increasing the load carrying capacity and hence delaying the local buckling of steel walls. From the experimental results shown Table 3 and Figure 3, the weld fillet location did not significantly affect the axial load carrying capacity of composite stubs. Samples with height of 50mm CWS50 and CWL50 had failure test loads approximately twice the theoretical failure load. This is believed to be a result of the concrete core being in a confined stress state allowing it to reach approximately 3 times the 28 days concrete compressive strength. The failure mode of tested composite stubs was a local buckling mode where all steel walls deformed outwards. No sign of weld fillet failure was reported for any sample.

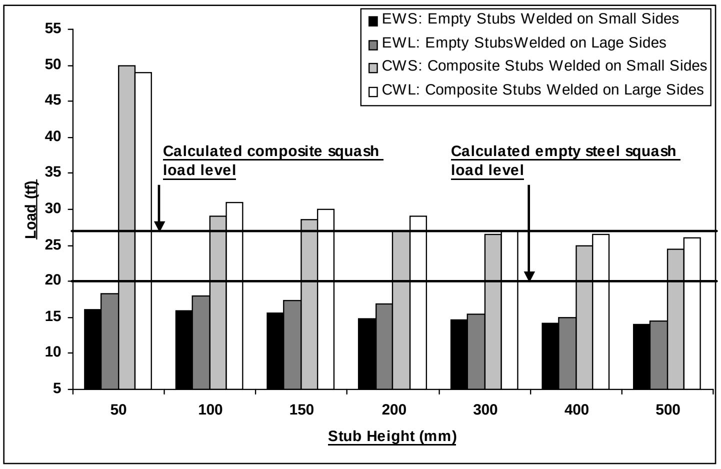

Figure 5. *Experimental failure loads comparison.*

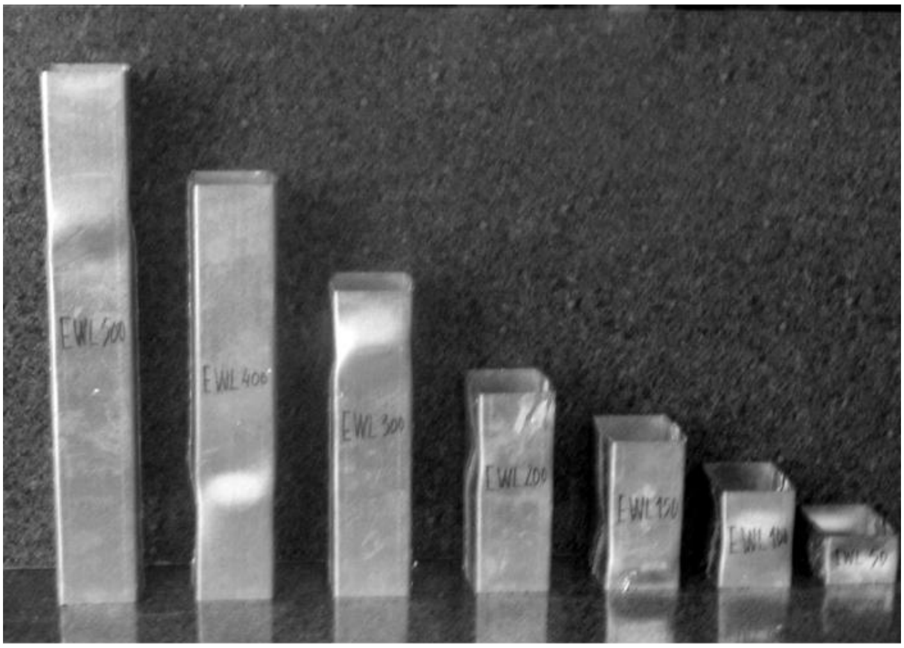

Figure 6. *Empty steel stubs EWL after test.*

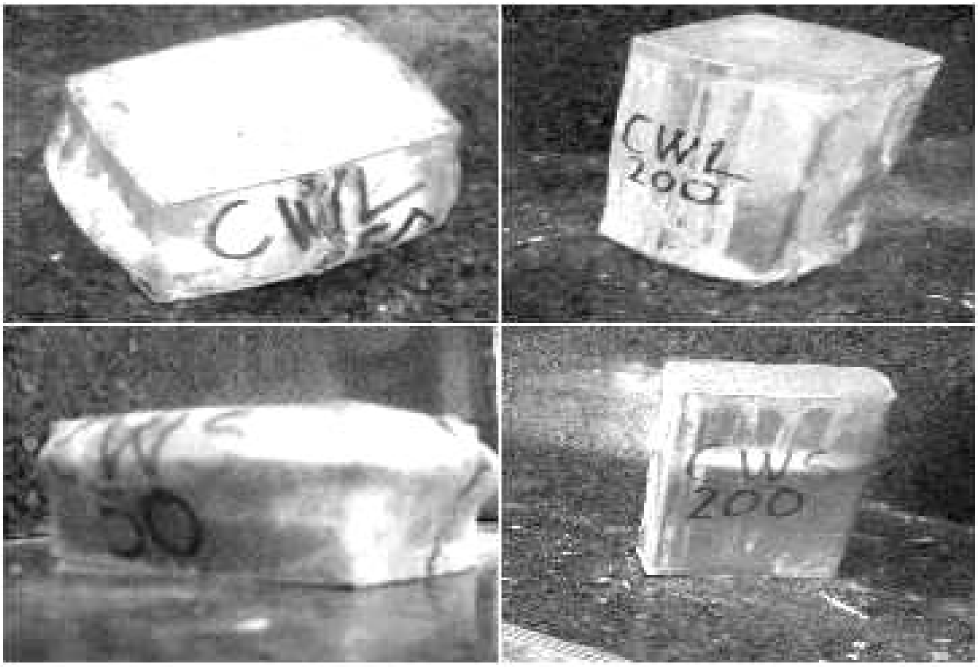

Figure 7. *Some composite stubs after testing.*

7. CONCLUSION

Empty cold formed and welded steel tubes with an H/t ratio of 50 suffered drastically from local buckling and reached loads below the theoretical steel failure load and increased from 5 to 13% when the weld fillets were located at the middle of the long side of the steel cross section. Composite stubs tested 28 days after casting, behaved well and reached maximum loads beyond or close to the corresponding theoretical failure load. This is a clear indication of the effect of the concrete core and composite steel-concrete action. The weld fillet location did not significantly affect the axial load carrying capacity in composite tubes. The failure mode of the samples was a typical local buckling mode with yielding of the steel and crushing of the concrete. No weld failure was reported in any samples. To understand the post-failure behaviour of the stubs cyclical loading was carried out and results of these tests will be presented in a future paper

References

[1] J. Zeghiche, *Concrete filled steel tubes*, PhD thesis, University of Annaba, Algeria, 2005.

[2] J. Zeghiche and al., *Résistance des tubes laminés à froid et soudés remplis de béton à base de granulats de laitier*, Séminaire National de Génie Civil, Sidi Belabes, Algeria, 2003.

[3] J. Zeghiche, N. Ferhoun, *Résistance à la compression des tubes laminés a froid et soudés remplis de béton à base de granulats de laitier*, 6éme Séminaire National de la Mécanique, Annaba, Algeria, 2006.

[4] Z.M.Bassam and S.G. Emhaidy, *Enhancing Filled-tube Properties by Using Fiber Polymers in Filling Matrix*, Journal of Applied Sciences, Vol. 5, Issue 2, 2005, pp. 232-235.

[5] You-Fu Yang, Lin-Hai Han, *Experimental behaviour of recycled aggregate concrete filled steel tubular*

columns, Journal of Constructional Steel Research, (article in press, 2006).

[6] J. Zeghiche and K. Chaoui, *Experimental behaviour of concrete filled steel tubular columns*, Journal of Constructional Steel Research, Elsevier 2005, Vol. 60, Issue 1, pp. 53-66

[7] J. Zeghiche and N. Ferhoune, *Experimental behaviour of concrete-filled thin welded steel stubs axially loaded case*, Proceeding of 6th International Conference on steel & Aluminium Structures, 2007, Oxford, UK.

[8] V.K.R. Kodur, *Performance of high strength concrete-filled steel columns exposed to fire*, Can. J. Civ. Eng., Vol. 25, 1998, pp. 975–981.

[9] M. A. Bradford, H.Y. Loh, B. Uy, *Slenderness limits for filled circular steel tubes*, Journal of Constructional Steel Research, Vol. 58, 2002, pp. 243–252

[10] M. Elchalakania, Xiao-Ling Zhaob, *Concrete-filled cold-formed circular steel tubes subjected to variable amplitude cyclic pure bending*, Engineering Structures, Vol. 30, 2008, pp. 287–299

[11] Zhong Taoa, Lin-Hai Hanb, Dong-Ye Wanga, *Strength and ductility of stiffened thin-walled hollow steel structural stub columns filled with concrete*, Thin-Walled Structures, 2008.

[12] Lin-Hai Hana, Guo-Huang Yaoa, Xiao-Ling Zhaob, *Tests and calculations for hollow structural steel (HSS) stub columns filled with self-consolidating concrete (SCC)* , Journal of Constructional Steel Research, Vol. 61, 2005, pp. 1241–1269.

[13] M. N. Baig, Fan Jiansheng, Nie Jianguo, *Strength of Concrete Filled Steel Tubular Columns*, Tsinghua Science and Technology, Vol. 11, Number 6, December 2006, pp. 657-666

[14] M. Mouli, H. Khelafi, *Strength of short composite rectangular hollow section columns filled with lightweight aggregate concrete*, Engineering Structures 29 (2007) 1791–1797.

[15] You-Fu Yang, Lin-Hai Han, *Experimental behaviour of recycled aggregate concrete filled steel tubular columns*, Journal of Constructional Steel Research, Vol. 62, 2006, pp. 1310–1324.