Malaysian Journal of Civil Engineering 27 Special Issue (1):57-67 (2015)

PERFORMANCE OF CONNECTIONS ADHESIVE-BONDED FOR COLD-FORMED STEEL

Rackford Bong* & Mohd Hanim Osman

Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

*Corresponding Author: *rackfordbong@gmail.com*

Abstract: In an attempt to cut the weight of the construction materials, the building industry is developing structural materials made from lightweight materials such as composites, cold-formed steel and aluminium alloys. The fabrication of these materials using traditional welding techniques is not feasible adhesive, thus bonding is at present being investigated as a potential method of connection. Limited in scope, the goal of this work was to produce adhesively bonded cold- formed steel structures to be used in the construction and to investigate the performance characteristics and failure mechanisms. The materials applied for this connection is a cold-formed steel 'C' channel section of hardened steel and epoxy adhesive. This paper reports the outcomes of mechanical tests on 18 samples of this connection. The performance of these connections is shown to depend on the comparative proportions of the bonded area. The primary conclusion is that the adhesive bonded joint gives additional strength to the connections of the subject area.

Keywords: *Cold-formed steel; hot-rolled galvanized steel; adhesive-bonded; epoxy adhesive; connections*

1.0 Introduction

The construction industry has recently focus their attention on three issues, which are reduction of material weight, an increase in the role of strengthening structure, and increase in the use of green engineering (Lee, Kim, & Oh, 2006). The industry is especially looking for ways to cut down the weight of material to enhance the high intensity level of structural performance and cost saving among others. The most effective ways to reduce a material weight is to use lightweight materials such as cold formed steel (Lee *et al*., 2006). Nonetheless, lightweight materials are not utilized for the roof truss structure because of the need of an effective jointing method and related application technology. To utilize the lightweight materials (cold formed steel) in roof truss structure, an effective joining method must be developed.

The conventional joining method, namely spot welding is not effective for joining cold formed steel materials, and thus, adhesive bonding has been used. Applying an adhesive for connecting cold-formed steel sections as a concept is not an altogether novel concept. According to researchers (Piekarczyk & Grec, 2012), the idea to apply adhesive bonding to the metal has its beginnings in the adaptation of phenolic adhesive used to bond wood initially and in the introduction of metal rubber joints in machinery. According to (H Pasternak, Schwarzlos, & Schimmack, 2004) the adhesive technique is a positive substance jointing. The additional material, namely the adhesive is needed to connect two segments. The dynamic, cohesive and adhesive forces in an adhesive layer are responsible for the potential strength is shown in Figure 1 respectively.

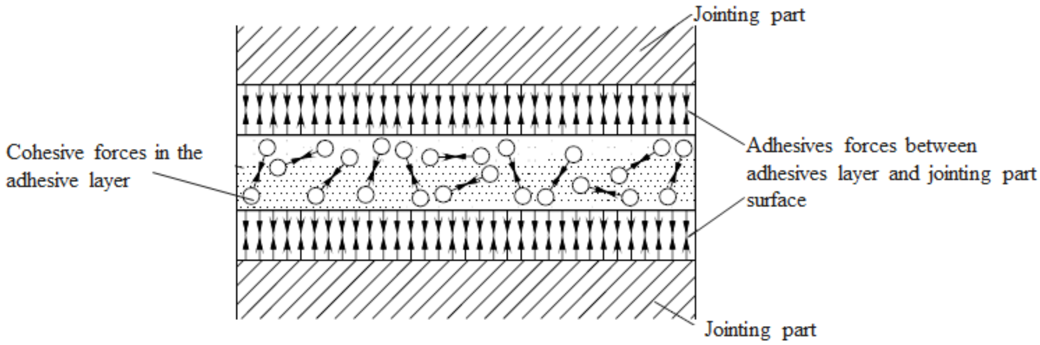

Figure 1: Adhesive and cohesive forces in an adhesive sealing

The adhesive bonding method offers advantages such as simple combination design and an easy joining process (Lee *et al*., 2006). One of the main benefits of adhesive is that it holds something together, holding out the stress trying to tear it aside (Nikarn, G.J, Kadam, 2006). According to Lee In parliamentary law to examine the applicability of these joining methods to roof truss structure, first performed basic tests on the effectiveness of these joints (Lee *et al*., 2006). In this composition, cold formed steel connection composed of cold formed steel ‘C’ section and hot rolled, galvanized steel was brought together by adhesive bonding was evaluated.

2.0 Materials and Method

2.1 Materials

The connected members in this study were formed of cold-formed steel C channel sections. Connections specimens, which were composed of cold formed steel and hot rolled, galvanized steel, were fabricated by adhesive bonding. Adhesive bonding is sometimes called chemical joining to differentiate it with mechanical joining (Nikarn, G.J, Kadam, 2006). The Young's Modulus uses 206GPa, and the tensile and yield strength were 410MPa and 250MPa respectively. The thickness was 1mm and the geometry of the bonded single lap joint is shown in Figure 2a & 2b respectively. The composite adherends are 250mm long and 75mm wide. The bonded area was 58.8mm x 75 mm. According to researcher (Makato, 1994) an adhesive joint fabricating condition was bonded to a surface by the epoxy adhesive into a single lap joint, as exemplified in Figure 3.

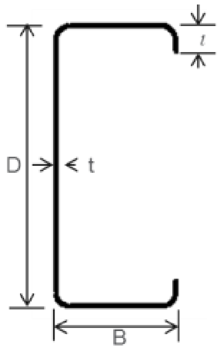

Figure 2(a): Dimension of single C channel

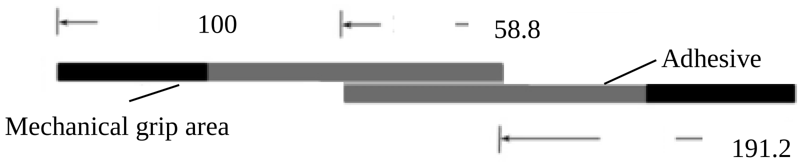

Figure 2(b): Geometric of the connections (all dimensions in mm)

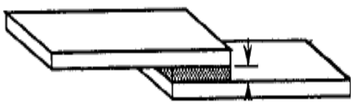

Figure 3: Single lap joint

According to researcher (Lee *et al*., 2006) there are two types of adhesive, namely heat cure and room temperature cure type. For convenience of the experimentation, the room temperature type adhesive was used in this work (Lee *et al*., 2006). The adhesive bond used to fabricate the adhesive-bond connections was Pioneer all-purpose adhesive is shown at Figure 4, which consisted of two components multipurpose thermosetting plastic materials such as A-Epoxide (red color) and B-Amine compound (white). Similar properties with the adhesive used in this experiment are presented in Table 1.

Table 1 Properties of adhesive (PLEXUS MA822 structural adhesive)

Chemical type	Two part
Cure method	25°C, 15 20 min
Shear strength(ASTM D1002)	18.6 – 20.7 N/mm^2
Tensile strength(ASTM D639)	20 – 22.7 N/mm^2

(Source:(Lee *et al*., 2006)

Figure 4: Pionner all-purpose adhesive

2.2 *Method*

The schematic drawing of the testing for the connection tests is shown in Figure 5. The connections specimens that were fabricated by adhesive bonding before the tensile tests are shown in Figure 6. The testing layout of the test loading ring including Universal Testing Machine, (UTM) and data logger is as shown in Figure 7. After attaining proper combination test pieces are fixed in a gripper and load was applied till the joint gets turn apart. The tensile loading was applied incrementally through a load actuator. Observation and recording of results were conducted, including loading data and displacement of the specimen. A total of 6 tests were carried out with 2 samples each and the results of load-deflection were plotted. For test specimen and experimental setup, refer Figure 5 and 6 respectively.

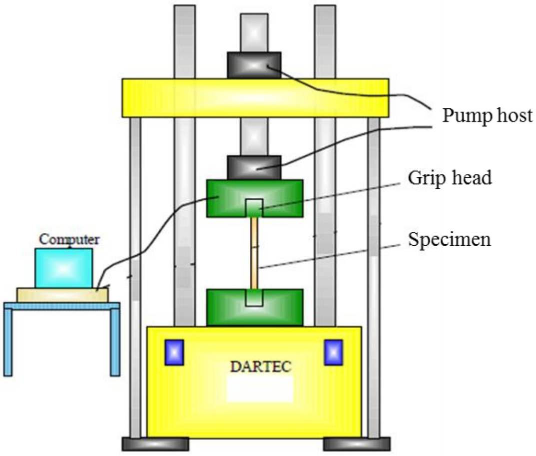

Figure 5: Universal Testing Machine (Yusof, 2010)


Figure 6: Specimens for tensile test


Figure 7: Universal Testing Machine

3.0 Results

3.1 Load-Displacement Relationship

The load-displacement curves of both connection types (cold-formed steel to Cold-formed steel and hot rolled galvanized steel to cold-formed steel) are represented in Figure 8 and Figure 9. Table 3 & 4 summarize the ultimate load, and the corresponding displacement, of each specimen's connections respectively. They also include the corresponding ultimate average load, Average adhesives thickness, design capacity values, and adhesives bonding strength (Kelly, 2006).

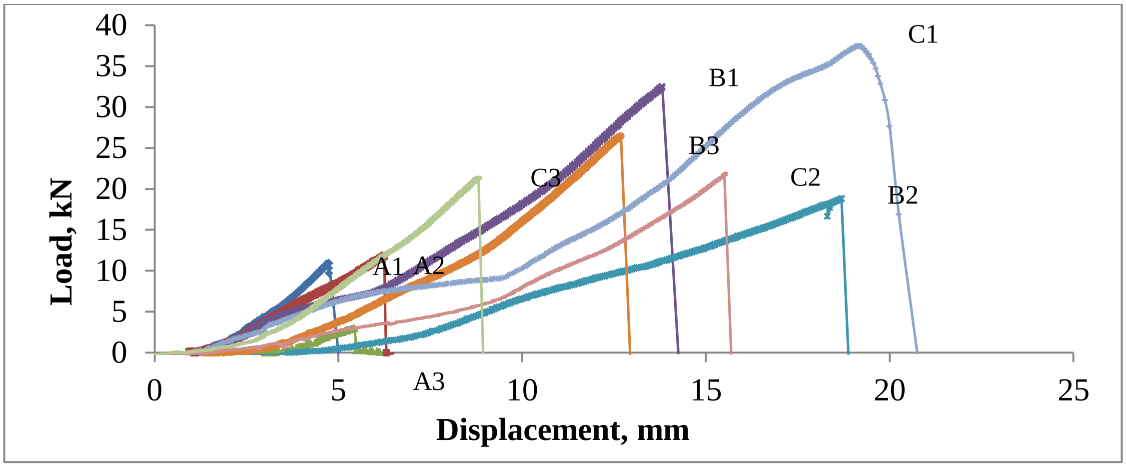

Figure 8: Load-Displacement curves for CFS-CFS joint type

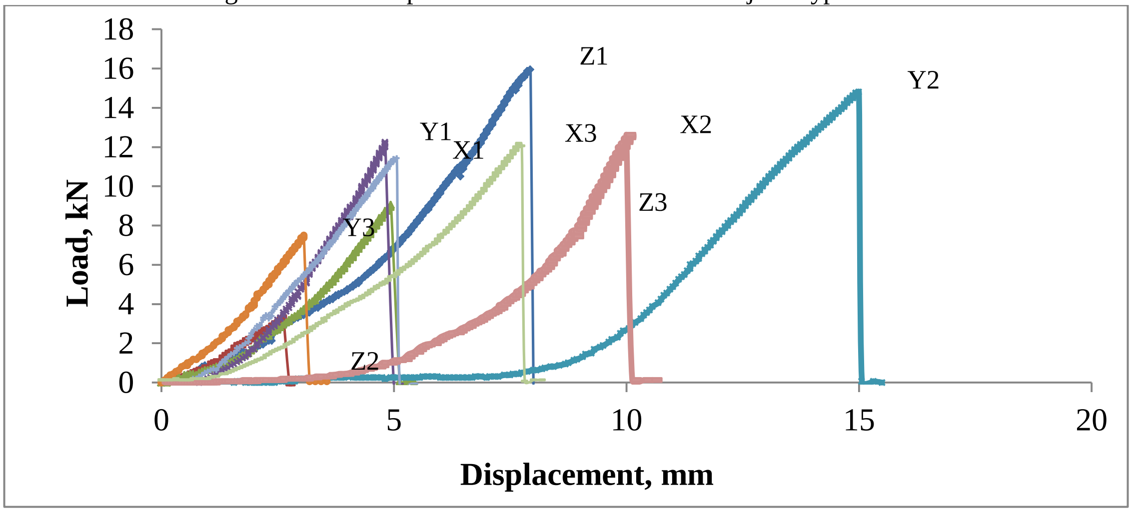

Figure 9: Load-displacement curves for GS-CFS joint type

Table 2: Test result for CFS-CFS

Spesimen	Bonded area (mm^2)	Measured resistance				F_c	f_a	Mode of failure
		F_u (kN)	Δ_u (mm)	F_{uAvg} (kN)	Thickness of adhesives t_a (mm)	x 10^3 (N)	(N/mm)	
A1	58.8 x 75	10.94	4.75					Cohesive crack
A2	58.8 x 75	11.88	6.25	8.59	1.60	79.4	1.95	Cohesive crack
A3	58.8 x 75	2.94	5.44					Cohesive crack
								Adhesive crack
B1	58.8 x 75	32.5	13.81					Adhesive crack
B2	58.8 x 75	18.81	18.69	25.92	1.53	79.4	4.41	Cohesive crack
B3	58.8 x 75	26.44	12.69					Cohesive crack
C1	98.2 x 75	37.44	19.19					Adhesive crack
C2	98.2 x 75	21.88	15.5	26.90	1.14	79.4	3.66	Adhesive crack
C3	98.2 x 75	21.38						Adhesive crack
m				20.47	1.42		3.34	

Table 3: Test result for GS-CFS

Spesimen	Bonded area (mm^2)	Measured resistance				F_c	f_a	Mode of failure
		F_u (kN)	Δ_u (mm)	F_{uAvg} (kN)	Thickness of adhesives t_a (mm)	x 10^3 (N)	(N/mm^2)	
Z1	58.8 x 75	15.94	7.94					Adhesive crack
Z2	58.8 x 75	3.31	2.63	9.44	1.92	79.4	2.14	Cohesive crack
Z3	58.8 x 75	9.06	5.06					Cohesive crack
Y1	78.8 x 75	12.25	4.81					Cohesive crack
Y2	78.8 x 75	14.81	15.0	11.52	1.91	79.4	1.96	Cohesive crack
Y3	78.8 x 75	7.50	3.06					Adhesive crack
X1	98.2 x 75	11.44	5.06					Adhesive crack
X2	98.2 x 75	12.63	10.00	11.52	2.25	79.4	1.64	Adhesive crack
X3	98.2 x 75	12.19	7.69					Adhesive crack
m				11.02	2.03		1.91	

As shown in Figure 8 & 9: As the load increasing constantly, load-displacement curves slope keeps descending for both type of connections (Lu, Huang, Fang, & Yang, 2012). Load-displacement curves for specimens CFS-CFS were identical except for specimens C1, which achieved higher ultimate load. The behavior is linear up to approximately 5 and 30 kN (approximately 40% of failure load). The average failure load was 20.47 kN and average displacement was 1.42 mm. The ultimate average adhesives bonding strength was 3.34 N/mm^2 but the manufacturer states a shear strength value of approximately 20 N/mm^2; the present test result is just 16% of the value given by the manufacturer. There are many factors that may have contributed to the degraded shear strength of the adhesive. One possible factor is the fabric layer (Kweon, Jung, Kim, Choi, & Kim, 2006).

Load-displacement curves for specimens GS-CFS were similar to those for specimens CFS-CFS. The behavior was linear up to approximately 4 and 16 kN (approximately 40% of failure load). The average failure load was 11.02 kN, 50% lower than for specimens CFS-CFS, and average global displacement was 2.03 mm. The ultimate average adhesives bonding strength was 1.91 N/mm^2, which is 40% lower than that corresponding to specimens CFS-CFS (3.34 N/mm^2) (Kelly, 2006).

The experimental capacity of connection is determined based on the maximum load achieved by each specimen as shown in Table 2 & 3. The adhesives bonding strength is calculated by dividing the ultimate load by contact area for each specimen

Example of Calculations

Cold-Formed Steel Ultimate Tensile Strength, $F = 410MPa = 410\ \frac{N}{mm^2}$

Cold-Formed Steel Tensile Strength, $F = 80\% \times 410\ \frac{N}{mm^2}$

$$F = 328\ \frac{N}{mm^2}$$

Design capacity of Cold-Formed Steel,

$$F_c = F \times Area\ of\ Section$$

$$F_c = 328 \frac{N}{mm^2} \times (((75 + 38 + 8) \times 2mm) \times 1mm)$$

$$F_c = 79376\ N$$

For CFS-CFS Adhesive bonding strength,

$$f_a = \frac{Fu,Load}{A,Contact\ area}$$

$$f_a = \frac{26.90 \times 10^3}{98.2 \times 75}$$

$$f_a = 3.65 \frac{N}{mm^2}$$

Hence $F_c > f_a$ the design capacity of cold-formed steel is higher than adhesive bonding strength. This expresses the extension of the area of adherence is essential in improving adhesive bonding strength. It is clearly shown here that the use of adhesive in connections is completely unsuitable without bolts.

3.2 Mode of Failure

According to Pasternak, the adhesive forces are effective between the adhesive layer and the jointing part surface. An adhesive crack occurs when there is a detachment between the both materials (H Pasternak *et al.*, 2004). Another possibility of failure mode is when "internal forces" are exceeded, causing the fracture to occur in the adhesive layer. This is a cohesive crack (H Pasternak *et al.*, 2004). Failure of specimens CFS-CFS and GS-CFS occurred in two major failure mode which is cohesive crack and adhesive crack as shown in Figure 10a & 10b respectively. Details mode of failure for each specimens was shown at Table 3 and 4 above.

(a) (b)

Figure 10: Mode of failure (a) cohesive crack (b) adhesive crack

4.0 Conclusion

The test results indicate the possibility of adhesive connections in cold – formed steel (H Pasternak *et al*., 2004). Eighteen connections specimens were examined to assess the performance of adhesive-bonded connections for cold – formed steel in which the method of connections is by an adhesive (Serrette *et al*., 2006). The performance characteristic of connection of cold- formed steel for cold-formed and cold- worked steel to hot-role galvanized steel is grounded on the load and the contact area. The results have also been compared to the theoretical calculations. It can be concluded as follows;

(i) Comparing the adhesive bonding strength of the connected sections, the adhesive strength of the cold- formed steel to cold-formed steel is greater compare to the cold- formed steel to hot rolled galvanized steel.

(ii) The mode of failure of cold-formed steel to cold-formed steel was cohesive crack. In contrast, the specimen's cold- formed steel to hot rolled, galvanized steel mode of failure was adhesive crack.

Overall, the maximum resistances were governed by failure at the adhesive part (Serrette *et al*., 2006). Specifically, small sticking area will carry a small force. Nevertheless, larger sticking area will carry a bigger force. Adhesives are an option to the usual techniques to connect steel members. It is necessary to create a base of calculation for practical applications (H Pasternak *et al*., 2004). Therefore, someone has to realize that adhesive bonding is not to be seen in competition with the established joining elements of steel construction. Rather the joining technique "adhesive bonding" offers the possibility to go new ways and to realize new constructions that were unimaginable using screws, rivets or welds (Hartmut Pasternak, 2004.)

References

Banea, M. D., & da Silva, L. F. M. (2009). Adhesively bonded joints in composite materials: an overview. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *223*(1), 1–18.

Kelly, G. (2006). Quasi-static strength and fatigue life of hybrid (bonded/bolted) composite single-lap joints. *Composite Structures*, *72*(1), 119–129.

Kweon, J.-H., Jung, J.-W., Kim, T.-H., Choi, J.-H., & Kim, D.-H. (2006). Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding. *Composite Structures*, *75*(1-4), 192–198.

Lee, M.-H., Kim, H.-Y., & Oh, S.-I. (2006). Crushing test of double hat-shaped members of dissimilar materials with adhesively bonded and self-piercing riveted joining methods. *Thin-Walled Structures*, *44*(4), 381–386.

Lu, L., Huang, G., Fang, W., & Yang, D. (2012). Numerical Simulation Analysis on Shear Bearing Capacity Experiments of Cold-formed Steel Self-drilling Screws Connection, *169*, 200–206.

Makoto, N. (1994). *Mechanism of Adhesion of Epoxy Resin to Steel Surface 1994.pdf* (p. 7).

Nikarn, G.J, Kadam, S. (2006). Shear Strength Analysis of Adhesively Bonded Single Lap Joint Method. In *Recent Advances in Materials Processing and Characterization*.

Pasternak, H. (2004). Adhering in Steel Construction-Advantages and Possibilities, 1–10.

Pasternak, H., Schwarzlos, A., & Schimmack, N. (2004). The application of adhesives to connect steel members. *Journal of Constructional Steel Research*, *60*(3-5), 649–658.

Piekarczyk, M., & Grec, R. (2012). Application of adhesive bonding in steel and aluminium structures. *Archives of Civil Engineering*, *58*(3).

Serrette, R., Lam, I., Qi, H., Hernandez, H., & Toback, A. (2006). Cold-Formed Steel Frame Shear Walls Utilizing, (April), 591–599.

Yusof, A. (2010). *Bending Behavior of Timber Beams Strengthened using Fiber Reinforced Polymer Bars and Plates*. University of Technology Malaysia.