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EXPERIMENT ON COLD-FORMED STEEL C-SECTION JOINT WITH SCREW AND ADHESIVE MATERIAL

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Abstract

Experiments were performed on the cold-formed steel C-section (CFS-CS) joints using the screw and adhesive material as the main subject of the study to assess the tensile stress-strain capacity. Since the connection has become the foremost aspect of the CFS-CS structure, a number of studies have been focusing to provide a better understanding with regard to the behavior of the *connection. Even more so, further studies have also been carried out focusing on alternate solutions to improve the connection capacity. Considering all the above, this paper discusses the influence of varying types of connection on the tensile behavior of CFS-CS elements with particular using the self-drilling screw and 3M Scotch-weld DP810 as an adhesive material. The configurations of the screw(s) used in this study were 1, 2, and 3, while the percentages of adhesive material being used were 50%, 75%, and 100%. The results showed that the use of a higher amount of adhesive does not significantly increase the load capacity, but alleviate the failure condition. The results also showed that all test specimens satisfy the minimum requirement according to design specifications.*

Keywords

Cold-Formed Steel, C-Section, Connection, Adhesives, Screws, Load-Deformation Capacity

1. Introduction

The increase of research and diversity of the commercial application dealing with the use of cold-formed steel (CFS) structures in Indonesia was launched with the introduction of the roof steel framing system for the residential building in the late 1990s. Although it was first applied to roof element, the advantage of the CFS section has resulted in broadening of its application to another type such as main structural framing (e.g. column, beam, racks and even mid-rise residential buildings). Some of the various needs could not be satisfied only by restructuring techniques using the current CFS, particularly in connection part. Since the standard connection for the CFS is screw and bolts, the research and development of the alternative connection of the CFS section have to be executed. Some particular connection element of the special shapes is necessary to make the connections for the CFS frames (Swensen *et al*., 2016; Komara *et al*., 2016) composed several types of CFS connection.

This paper presents the experiments conducted to develop a new alternative connection and apply it to the roof truss framing system, which could be further evaluated for other

Table 1: *The configuration of connection specimens*

Specimen	Configuration		
	Type 1	Type 2	Type 3
A	S1_A3M50	S2_A3M50	S2_A3M50
B	S1_A3M75	S2_A3M75	S2_A3M75
C	S1_A3M100	S2_A3M100	S3_A3M100

where: S = screw, 1,2,3 = number of screw, A = adhesive, 3M = 3M scotch-weld DP810, 50, 75, 100 = percentage of adhesive (%)

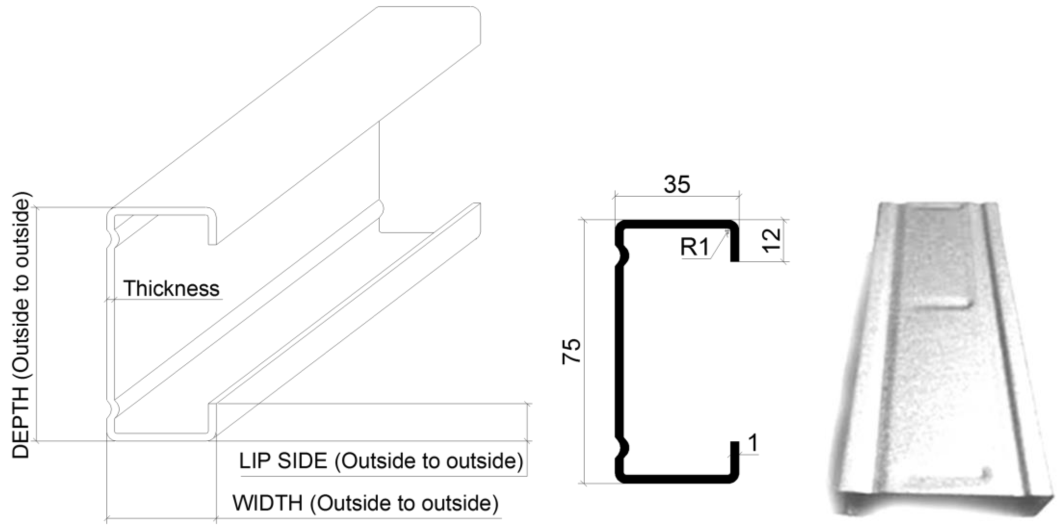
construction systems. The performance of the connection is primarily dependent on the number of screws and the use of adhesive. Anwar *et al*., (2014, 2015) were among the first to study the influence of self-drilling screw and the adhesive material on the connection of element subjected to tensile stress. The result showed that all types of connections were enabled to enhance the capacity and minimize the fracture of the element. However, the study did not provide extent insights into the adhesive effect; therefore, further research should be performed by means of providing improved insights. This can be done by increasing the percentage of adhesive used in the connection. In addition, different types of adhesive material should also be evaluated as a means of collecting more information which material works best to improve the capacity of the connection thereby giving the optimum alternative.

This research focuses on improving the connection behaviour of lightweight steel roof truss structure by utilizing a combination of screws and adhesive. The use of adhesive in connection lightweight steel roof truss structure is to provide an equitable distribution in the joint areas and increase the shear capacity. In addition, the combination of the addition of adhesive on the connection will produce a lightweight steel roof truss structure rigid. The adhesive connection will increase the rigidity of the structure of between 30% to 100% before bending (Brandon, 2010).

Table 2: *Mechanical properties of CFS-CS*

Nominal grade	550 Mpa
Nominal thickness	1.0 mm
Elastic modulus	168.9 GPa
Yield stress, Fy	590 MPa
Yield strain	0.45%
Ultimate stress, Fu	600 MPa
Ultimate strain	2.86%

Following the above statements, it is strengthening the connection using screws and adhesive on the CFS frame structure can be applied to analyze the behavior of the connection between all elements of the roof frame structure. Optimization of the connection using the combination of the screw and adhesive is examined experimentally, to obtain the optimum performance of the structure. The consideration of various configuration was also taken i.e. the number of screws, 1 to 3 installed screw and percentage of adhesive material, A3M. The behavior of the structure such as the distribution of stresses and strains and damage to the connection surface (surface damage) as well as the influence of the number of screws and the broad field of screw connection and adhesive will be further discussed. Results are expected to improve the connection behavior CFS roof truss structure thereby providing such sustainable and eco-friendly building infrastructure.



(a) (b) (c)

Figure 1*: Section geometry and dimension of CFS-CF section (unit; mm);*
(a) The CFS-CS 3D section, (b) Section geometry, (c) The use material

Table 3: *Tensile coupon test of CFS-CS*

Specimen	**Yield stress F_y (MPa)**	**Ultimate tensile stress F_u (MPa)**	**F_u / F_y**	**Stroke (mm)**
Sample 1	559.3	611.2	1.093	17.7
Sample 2	548.7	589.3	1.074	16.2
Sample 3	601.5	631.2	1.049	18.4

2. Section Geometry and Material Properties

2.1 Section Geometry

The CFS-CS made by cold-rolling with the clinching technique was used throughout this study. The flange width and web depth of the CFS-CS were 35 and 75 mm respectively, and the thickness was 1.0 mm. The pitch of clinching on the web was 5 mm in staggered position. The CFS-CS section geometry is shown in Figure 1 with the section properties summarized in Table

2. The effective area was estimated in accordance with American Iron and Steel Institute (AISI) specifications, assuming that the section was under uniform compression.

2.2 Material Properties

The material grade of the CFS-CS was G550. The nominal yield and ultimate strength was 590 and 600 MPa respectively. The first test specimens in the form of tensile coupons were cut from the flat area of the CFS-CS sections. The test summary of tensile coupon specimens is

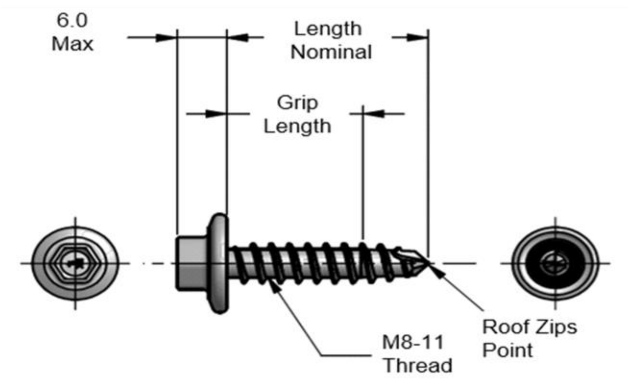


Figure 2. Screw section detail

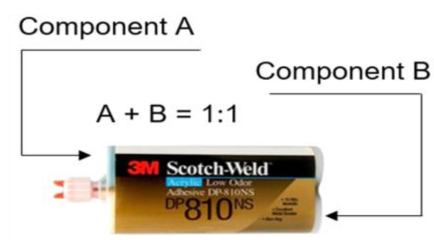


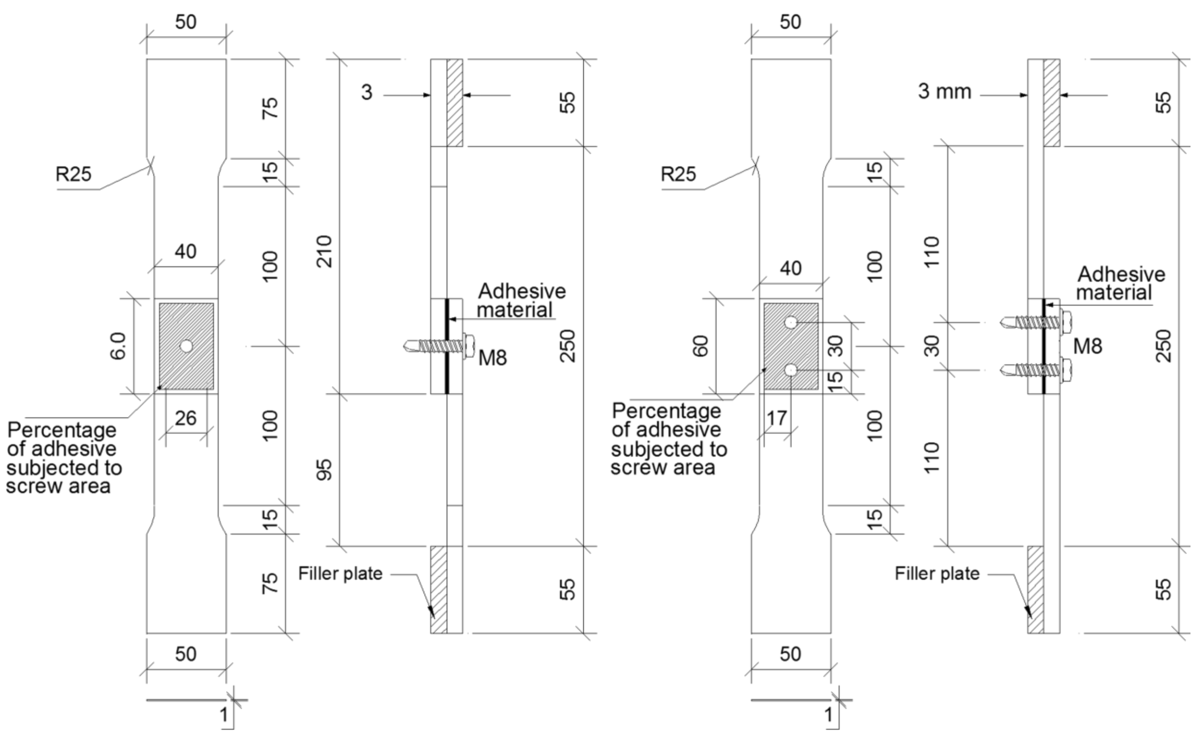
Figure 3. 3M Scotch-weld DP810 material

Table 4: *Tensile coupon test of 3M Scotch-weld DP810*

Specimen	Maximum load capacity (kN)	Average (kN)	Elongation (%)	Average (%)
Sample 1	26.68	27.75	8.35	8.99
Sample 2	28.43		9.12	
Sample 3	28.15		9.51	

presented in Table 3. From what is seen in the table, it is evident that the yield and ultimate tensile stress properties obtained from the material investigation are higher than the nominal yield and ultimate stress specified in the standard specification. Nevertheless, the tensile deformation is found to be lower than the normal mild steel where it is shown that the deformation is ranging from 16 to 18 mm with the average deformation of 17.43 mm.

The diameter of the screws type "M8-11 Hex" installed at the overlapping area of the CFS-CS specimen was 8 mm, and the nominal shear strength capacity was 1.7 kN according to the specification specified by the manufacturer (see Figure 2). The length and the grip length were 20 and 12 mm respectively. The adhesive material used in this study was 3M Scotch-weld DP810. This adhesive property presented in Table 4 is based on adhesive epoxy or glue epoxy, low odor adhesive which is ideal for any material. The material also provides high shear and peel strength as well as toughness for impact resistance although it still becomes major issues due to harsh fumes or flammability. As shown in Figure 3, this adhesive material consists of two

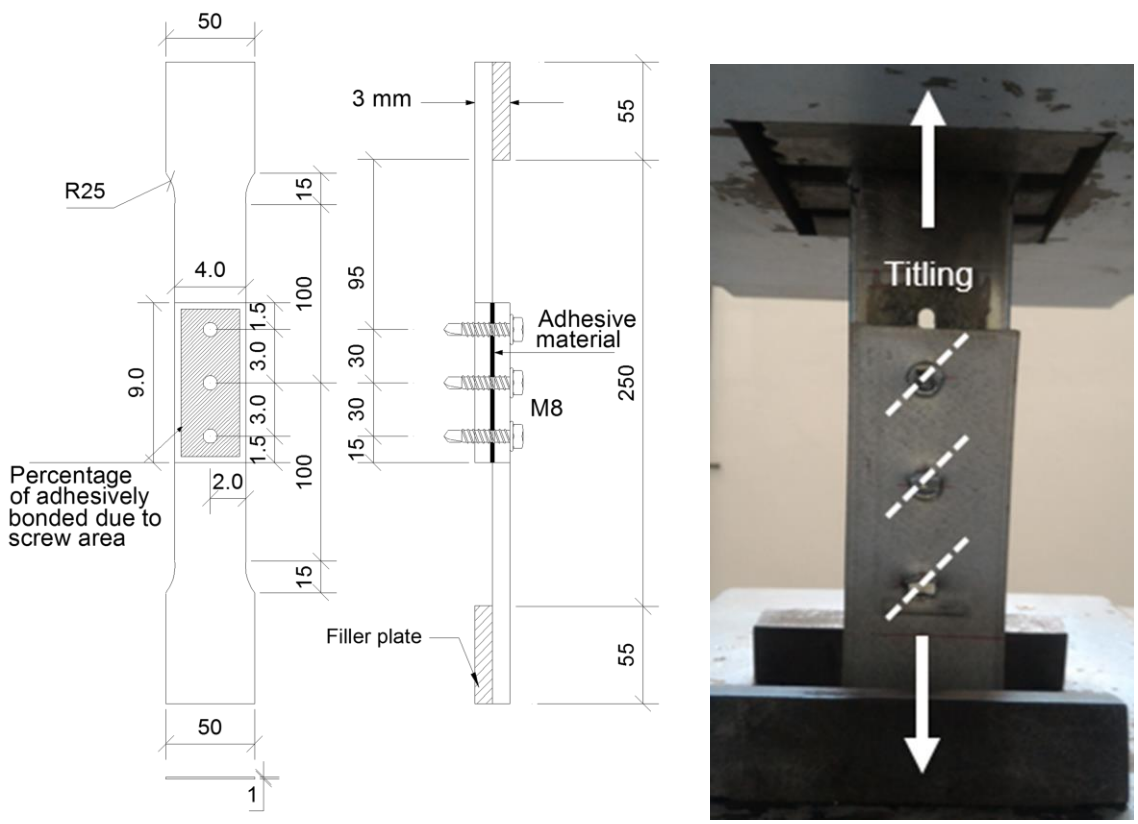


(a) (b)

components, namely A and B, indicated by grey color. The mixed ratio is 1:1 thereby given the dark grey color.

3. Connection Test Procedures

Experimental investigations into the performance of connection in the CFS-CS members were conducted with the rate of the load being applied to each sample ranging between 1.15 to 11.5 MPa/s. The samples were tested using the universal testing machine with the capacity of 50 kN. The testing configurations are shown in Figure 4. In this study, the specimens were initially cut into a shape in accordance with ASTM E8/E8M-09. Adhesive material was first given in the overlapping area.



(c) (d)

Figure 4: Test set up of specimen (unit; mm); (a) S1_A3M50, (b) S2_A3M50,

After five minutes, screw(s) were then installed within the overlapping area as well. It should be noted that the pattern configuration of the screw was also taken into account. This is to ensure that this research would cover at least what is being represented for the actual roof framing system. The basic pattern for the design of the CFS-CS members was in accordance with the design code ASTM E8/E8M-09 and AISI S100 in which the minimum spacing of each screw was 3d where d is the diameter of the screw.

When finishing the material preparation, each of test specimens was then prepared and set to the machine by gripping the two ends using two grips provided by the machine. It is worth to mention, during the test, the stress and strain readings were automatically recorded by the machine. Therefore, it was not necessary to use linear variable displacement transducer, and load cell as the machine could cover all the test data. The stress was calculated based on the parameters of tensile load and cross-sectional area at the weak part, while tensile strain was then measured by dividing the actual deformation to the initial gauge length. Detail of stress and strain calculations are expressed in Equations (1) and (2). It is of importance to note that the cross-sectional area and initial gauge length must be measured prior to undertaking the test.

$$\sigma_t = \frac{F}{A} \quad \text{.... (1)}$$

$$\varepsilon = \frac{dl}{l_o} = \frac{\sigma}{E} \quad \text{.... (2)}$$

where	F	=	load at failure in N
	A	=	original cross-sectional area of the specimen (in m^2) at the narrow section
	dl	=	change of length (m, in)
	l_o	=	Initial length (m, in)
	ε	=	Strain - unitless
	E	=	Young's modulus (modulus of elasticity) (N/m^2 (Pa), lb/in^2 (psi)) Young's modulus can be used to predict the elongation or compression of an object

4. Result and Findings

The experimental results presented in this paper only provide a number of limited data of CFS-CS. Given that it is a necessity to perform further research with extent insights to collect more information regarding the behavior of this type of structure. Three types of configuration of

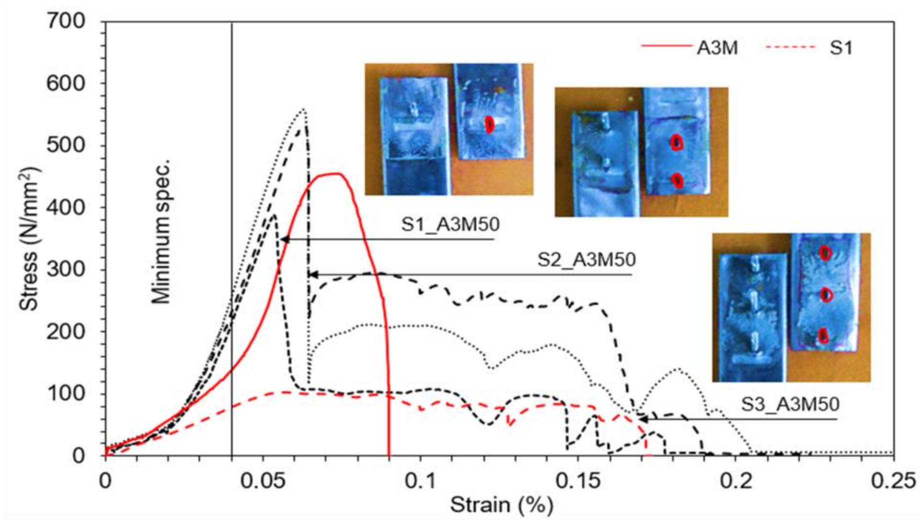


Figure 5. Stress-strain curve diagram; the number of screws and 50% percentage of adhesive

Figure 5: *Stress-strain curve diagram; A3M50*

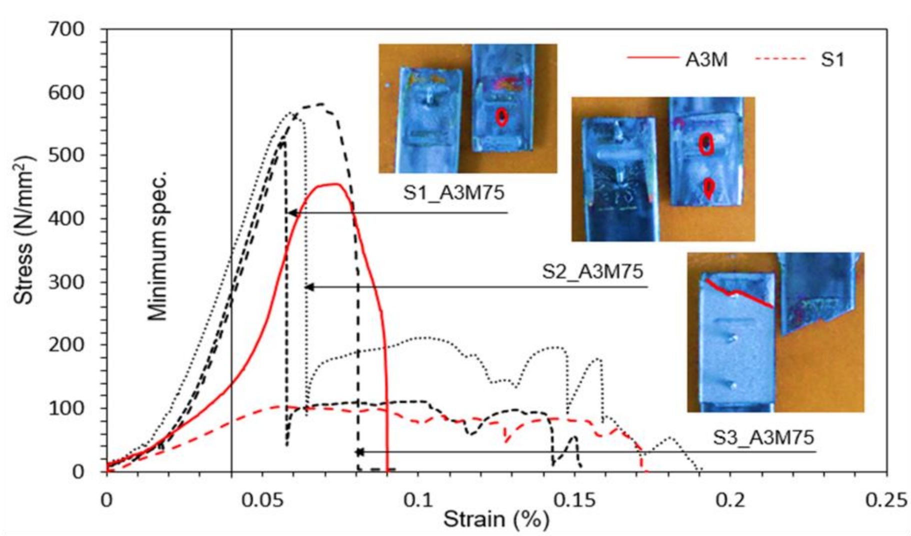


Figure 6. Stress-strain curve diagram; the number of screws and 75% percentage of adhesive

Figure 6: *Stress-strain curve diagram; A3M75*

screws have been used on the single lap joint specimen with each of type consisting of three specimens. Comparison of the test results concerning the facture mechanism and behavior of stress-strain are addressed in this section (see Figures 5 through 7) along with the summary of the maximum load and stroke capacity presented in Table 5. Each figure represents the percentage of adhesive material being used, starting from 25%, 75%, and 100%. Given this percentage, the following terms are then used to corresponding specimen i.e. A3M50, A3M75, and A3M100.

From what is seen in Figure 6, it should be mentioned that low amount of adhesive material generates low strength in terms of load capacity. Surprisingly, even with the increase of the percentage of adhesive material by 25% (A3M75 specimen) does not significantly increase the load capacity. The only exception is that the failure mechanism differs one another. In spite of tilting condition occurred for both types of specimens, the coherency of a higher amount of adhesive material is evident. It is also shown that the tilting failure of A3M75 specimen is relatively subtle, whereas A3M50 specimen shows the opposite trend (for illustration see photos overlaid in Figure 5 through 6. Differ to previous results; Figure 7 depicts the behavior of A3M100 specimen whereby all of the specimens indicate the connection is much higher than the

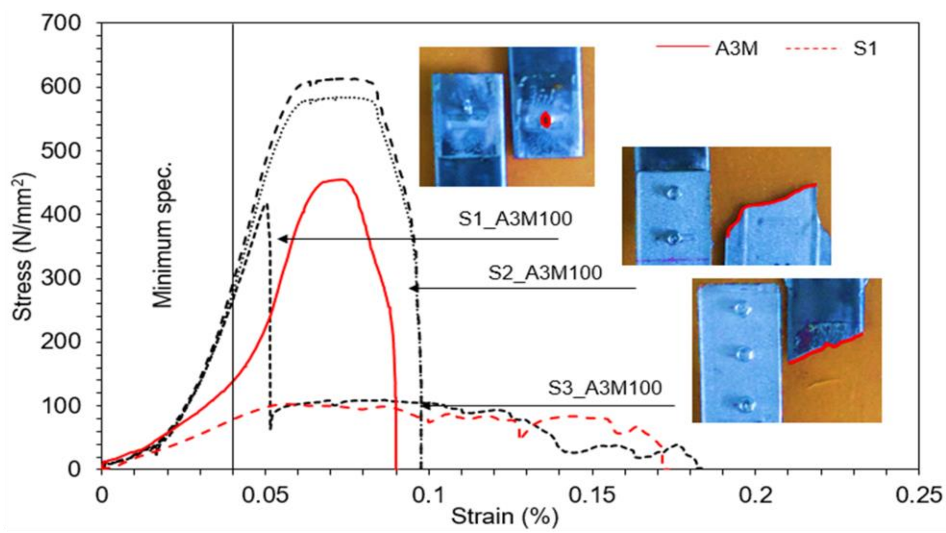


Figure 7. Stress-strain curve diagram; the number of screws and 100% percentage of adhesive

Figure 7: *Stress-strain curve diagram; A3M100*

section capacity. Therefore, failure takes place in the outside of weak section instead of in the connection. In the overall situation, it is worth to mention that the effect of screw configuration does not significantly affect the way the improvement of load capacity.

Referring to the prior research from Komara et al. (2017) of the screw connection and adhesive connection using the identical parameters to this present work. It is shown that the combination of screw and the adhesive material applied to the specimen could give a better behavioral response. It can be said that the load and deformation capacity is nearly twice higher than that of the screw connection and/or adhesive connection. In addition, the combination of these two distinct materials can also alleviate the tendency of a significant failure condition, for instance, the tilting condition is way more insignificant due to the little damage occurred at the hole of the screw.

Shown in Figures 5 through 7 are the stress-strain relationship of CFS-CS specimens compared to the minimum specification specified by AISI S100. It can be seen from Table 5 that all specimens satisfy the minimum requirement.

Table 5: *Comparison of combination connection capacities and failure mechanism*

Specimens	Maximum load capacity (kN)	Stroke (mm)	Failure mechanism	Explanation
S1_A3M50	17.81	8.12	Low ductility	Large tilt angle and pull-through
S2_A3M50	25.61	15.32	Medium ductility	Large tilt angle and pull-through
S3_A3M50	24.38	19.51	Medium ductility	Large tilt angle
S1_A3M75	24.32	18.72	Medium ductility	Low tilt angle and pull-through
S2_A3M75	26.05	20.82	High ductility	Low tilt angle
S3_A3M75	26.67	21.11	Strong	Tear-out
S1_A3M100	20.15	18.14	Low ductility	Low tilt angle
S2_A3M100	26.79	10.25	Strong	Tear-out
S3_A3M100	27.78	10.79	Strong	Tear-out

where: S = screw, 1,2,3 = number of screw, A = adhesive, 3M = 3M scotch-weld DP810, 50, 75, 100 = percentage of adhesive (%)

5. Conclusions and Recommendations

The behavior of CFS-CS elements with the varying configuration of screw and adhesive material is presented in this paper. The emphasis has been made on the increase of the amount of adhesive material to improve the performance of the elements. The results are also compared to the minimum specification in accordance with AISI S100 and ASTM E8/E8M-09. With regard to the results of experimental tests, the following conclusions can be drawn:

1) The combination of screw and adhesive material on the connection can increase the load and deformation capacity twice higher than only using screw connection or adhesive material.
2) Tilting failure of the combined screw-adhesive material is found to be more insignificant than screw-only-connection
3) The increase in load capacity is note relatively noticeable in spite of the usage higher amount of adhesive.
4) All test specimens in the present work meet the minimum requirement as specified in design specification(s).

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