Indra KOMARA[1]

Kıvanç TAŞKIN[2]

Endah WAHYUNI[3]

Priyo SUPROBO[4]

[1, 3, 4] Institut Teknologi Sepuluh Nopember, Indonesia
Civil Engineering Department, Faculty of Civil Engineering and Planning
[1, 2] Anadolu University, Turkey
Civil Engineering Department, Faculty of Engineering
Email: indra12@mhs.ce.its.ac.id, kıvanct@anadolu.edu.tr, endah@ce.its.ac.id, priyo@ce.its.ac.id

THE EXPERIMENTAL STUDY OF COLD-FORMED STEEL TRUSS CONNECTIONS CAPACITY: SCREW AND ADHESIVE CONNECTION

Keywords: Adhesive, screw, capacity, connection, cold-formed steel,

Abstract

A series of connection tests that were composed of Cold-Formed Steel (CFS) sections were made to investigate the capacity of connections in a roof truss frame. The connection is controlled by using the two-different type of connection i.e. screws connection and adhesive connection. The variation of screws is also added applying 1 screw, 2 screws, and 3 screws. On the other hand, the percentage of adhesively material is increased by the total area of screws connection which is 50%, 75%, and 100%. Behaviors illustrated by each connection are examined, and the design capacities projected from the current CFS design codes are appealed to the experimental results of the connections. This research analyses the principal factors assisting in the ductile response of the CFS truss frame connection measured to propose recommendations for connection design, and novelty so that the connection respond plastically with a significant capacity for no brittle failure. Furthermore, the comparison connection was considered for the analysis of the connection capacity, which was estimated from the specimen's maximum load capacity and the load-deformation behavior. This research is also considered to face the problem of significant fracture mechanism and used as a further alternative solution.

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[1] Master Candidate, Institut Teknologi Sepuluh Nopember, and Anadolu University
[2] Asst. Prof. Anadolu University
[3] Assoc. Prof. Institut Teknologi Sepuluh Nopember
[4] Prof. Dr. Institut Teknologi Sepuluh Nopember

1. Introduction

Cold-Formed Steel (CFS) structures are one of the most prevalent used types of construction for residential low-rise buildings in Indonesia due to their low cost, ease and fast of construction, thin but have strength to resist lateral forces. In this type construction, the CFS roof truss frame is more commonly used, however in some cases it is possibly used as the main frame of the building. In that matter, The CFS becomes a highly competitive choice to structure development and improvements. To pursue the optimal design that can produce the well-managed cost of construction, the improvement of the framing connection is also completed, in specific, could increase the capacity of the CFS construction system without making the significant modification e.g. structural system and framing materials. This research study is conducted comparative evaluations for optimization of alternative connections, screws and adhesive connection. A number of screws are chosen for comparison with those that are presently stated for trusses' connections, expressed 2d and 3d with 1 screw, 2 screws, and 3 screws installed. In fact, the adhesive is also considered to be added in the connection based on the total area of a screw connection. It is implied by the percentage, instantly made by 50%, 75%, and 100%.

The evaluation of the vary connections is illustrated on the capacity of the testing specimen. The specimen capacities are reported by the maximum load capacity that was declined by the connection; screws and adhesively connections are included separately. Then, it is also explained the load-deformation behaviour analogously as the comparison of the experimental analysis.

2. Previous Study

In recent years, the study of the developments of the CFS, particularly from low-rise to mid-rise building, has been enhanced rapidly. Rogers et.al. [1] conducted by the experimental testing method of screwed shear connections with the single overlap specimens. The experimental test was varied the screw type and the number of screws in the connections to predict both the capacity and the failure mode of the connections. In fact, the result showed that none of the specimens failed in mere bending or titling. It is found that when the thinner sheet is toward to the screw head, bearing failure becomes more possibly happened.

Yong et.al. and Peköz [2, 3] reported an experimental test for CFS with self-drilling screw subdued in single shear mode and tension mode. In this case,

self-drilling screw expressed a better moment capacity and stiffness contrast to the conventional joint. The analysis is also considered to overcome the effective modulus properties e.g. kind of lips, flanges and web dimension subjected to Australian and American sections.

Yan and Young [4] investigated the CFS for roof sheeting in connection with a self-tapping screw at ambient and elevated temperature. It could be claimed that the failure of the connection is also proceeded by the alteration of temperature. The significant temperature may affect the direct failure of the structure. From that experiment, it needs to be evaluated for the combination types of connection that could possibly overcome that matter. In addition, Wahyuni et.al., [5-8] and Budiman et.al [9-10] evaluated a failure mechanism on steel structure subjected to various standards that could be considered as another research parameter.

A various series of isolated screwed joints is also conducted by Serrette and Peyton [11]. The analysis was held in total 12 specimens of beam-to-column connection. It is implied the different configurations and likens to Eurocode as an analytical model. The result is shown that the initial stiffness of the joint increased as the beam depth increased. Anwar et.al. and Komara [12-15] analyzed the proposed design of CFS by using adhesive and self-drilling screw material implemented by the tension test method. In this study, non-standardized sections were used. It is stated to alternate the connection type only. From that case, the study is further analysis by using standardized profile and using comparative adhesive material that commonly used in Indonesia.

3. Experimental Program

The connection strength capacity involved experimental testing of single lap connection of CFS sheets. One type of sheet thickness, 1 mm is implied, and self-drilling screw M8 was studied. Specific to this research was the study of the influence of the two type of connection with are added the number of screws and the same spacing of the screws. The screw connection is used to be a parameter point to an adhesive connection. The maximum number of screws in connection are 3 screws with the simply forming of geometric patterns and conducted with the minimum spacing as required, 2d to 3d, d is expressed as the outer diameter of the screw. The specification for the design of the CFS structural members [16-17] assigns a minimum of spacing. In this analysis, 2d spacing was classified as the minimum screw spacing. It is being used to be the main parameter coz the screw heads, 8 mm, interfered at a spacing less than 2d. Then, 30 mm spacing was transversally maintained.

Fig. 1. Adhesive material based on epoxy;
(a) 3M Scoth-weld DP810,
(b) Sikadur 31 CF Normal

Source: own research

Further, the adhesive connection is designed subjected to screws connection. The total area of screws connection is used as a parameter, and the percentage of adhesively material is implied to the connection. Percentage of adhesive material is being made 50%, 75%, and 100% compared to screws respectively, 1 screw, 2 screws and 3 screws. This is to propose whether either of these alternative connection types is a reliable replacement option which could improve or use as the alternative for CFS framing connection system. All connections are tested in angles of 90˚. That is assumed as simply roof truss member's connection.

A. Specimen Test

Specimen test set up is presented in Figure 2. For installing of the screws were adhered to code [16, 17]. The section material properties of CFS and adhesive material are in Table 1 and Table 2, respectively.

The connection pattern was centered transversally on the CFS section, with the first occurred screws at the minimum distance at the longitudinal position of the CFS sections sheet. As a matter of fact, the minimum distances between the transversal position were always exceeded. The same condition is used for the adhesive connection. It should be mentioned that adhesively connection arrangements were assembled with no-space parameter inputted but, it is controlled by the total area and the volume of material.

The adhesively material is added as an alternative using Sikadur 31 CF Normal, and 3M Scoth-weld DP810 expressed on Figure 1. Two necessary adhesive materials are used to be able to present the same strength as substitution of screws or represent the better connection condition. The percentage of adhesive is applied due to the enhancement of the number of screws. The percentage of proposed design of each connection are shown in Table 2.

Table 1. Mechanical properties of cold-formed steel truss's material

Nominal grade	550 Mpa
Nominal thickness	1.0 mm
Elastic modulus	168.9 GPa
Yield stress, Fy	592.3 MPa
Yield strain	0.45%
Ultimate stress, Fu	617.25 MPa
Ultimate strain	2.86%
Fu/Fy	1.04

Source: own research

Table 2. Mechanical properties of adhesive material

Property	Sikadur 31 CF Normal	3M Scoth-weld DP810
Base	Epoxy resin	Accelerator epoxy
Shear Strength (MPa)	20	25
Strength (MPa)	50	75
Working time (min)	30	10
Specific gravity	-	1.07

Source: own research

B. General Result

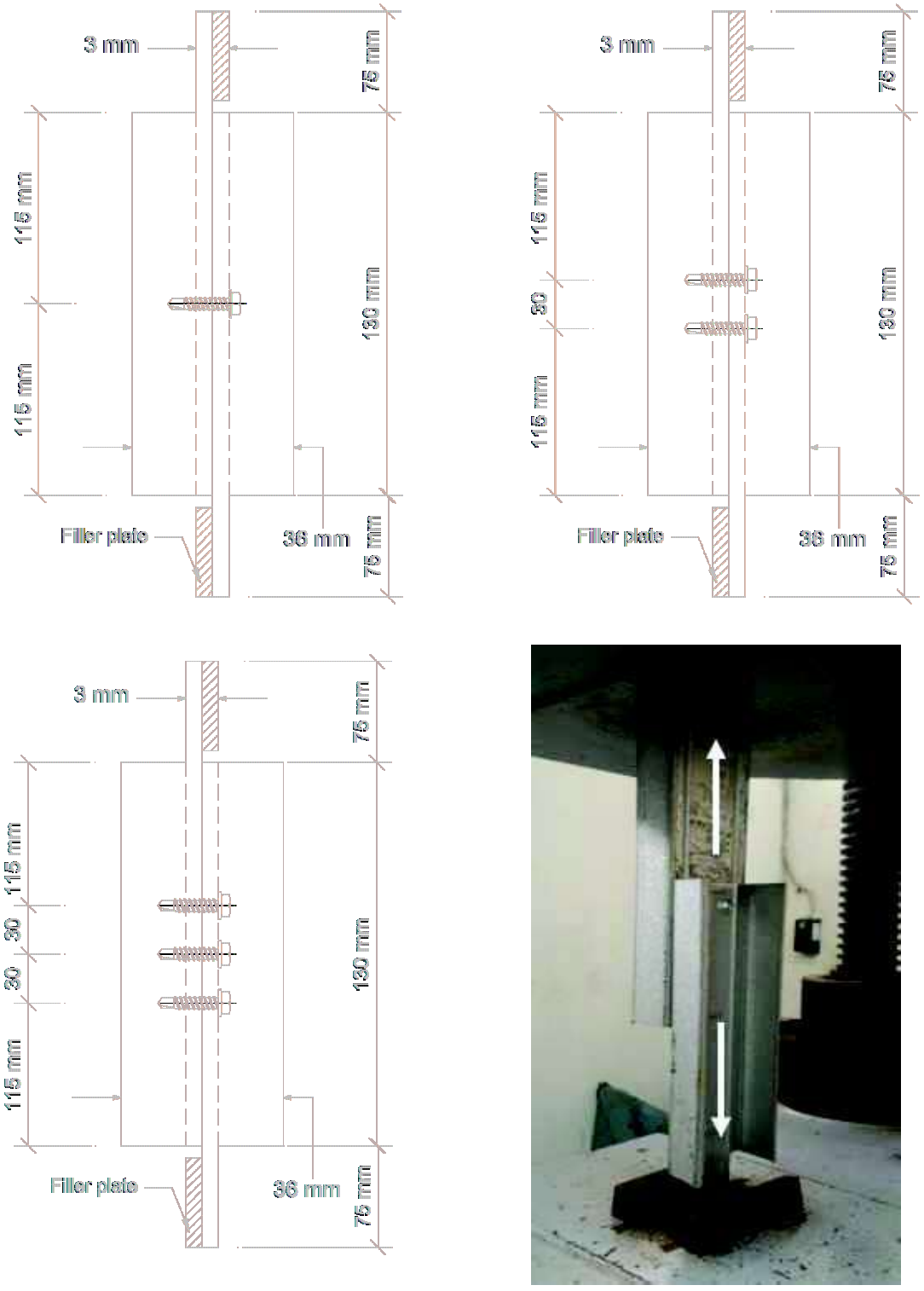
Characteristically, for a maximum installed number of screws, the section would fracture. When fracturing of the section taken place, it almost took in the section which had the screws threads exposed, rather than the section toward the screw head.

Table 3. The configuration of connection specimens

Specimen	Configuration		
	Type 1	Type 2	Type 3
Sikadur 31 CF Normal	50%	75%	100%
3M Scoth-weld DP810	50%	75%	100%
Screw Connection	1 screw	2 screws	3 screws

Source: own research

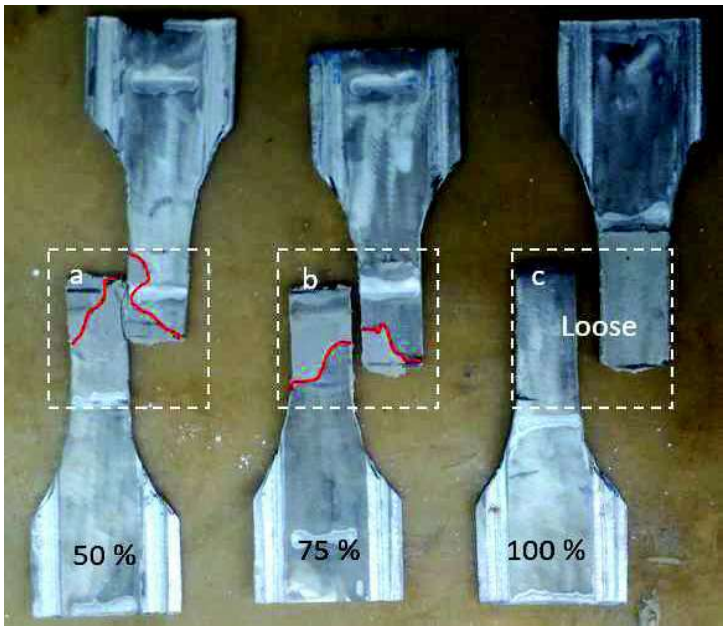
Fig. 2. Overall test set up for evaluating connection capacity



Source: own research

The strength of the screw was counted based on the failure load and the number of screws pattern. Fact, increasing the number of screws decreased the strength. In the other hand, the adhesively material is also compared. The strength capacity of adhesive connection is increased as the percentage of the used adhesive taken, but the different behavior of failures is expressed. For the percentage of 50% adhesive, the failure is occurred by the coherence of adhesive itself. The direct loose of each sheet happens in this connection. When you increased the percentage of the adhesive, instantly 75% and 100%, the failures are practically ensured nearly the head of test holder. It is presented in the Figure 3 and Figure 4 in order.

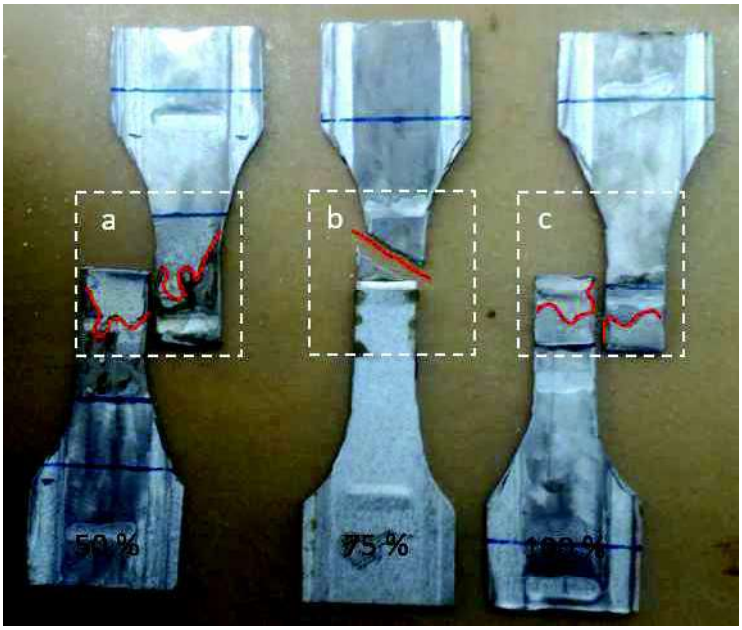
Fig. 3. Typical adhesively connection failure of Sikadur 31 CF Normal; (a) Percentage 50%, (b) Percentage 75%, (c) Percentage 100%



Source: own research

Illustrated by the Figure 3 above, pooped-off happened in almost all connection condition. It is stated that coherence of Sikadur 31 CF Normal should be controlled in advance, especially at the minimum working time which is 20 min more late than 3M Scoth-weld DP810. While this failure is consistent with the failure mode that occurred in coherence area, the other adhesive specimens exhibited significantly different failure modes as acquainted in Figure 4. Tearing failure of the section away from the connection occurred at variation (b) Resemblance of each parameter is performed respectfully in Table 4.

Fig. 4. Typical adhesive connection failure of 3M Scoth-weld DP810; (a) Percentage 50%, (b) Percentage 75%, (c) Percentage 100%



Source: own research

C. Design Equation

A design equation was initiated that permitted calculation of the bearing or bearing and titling connection strength subjected to a single-screw strength equation. The design equation is presented below by (1) which are followed by the other equations, (2) and (3).

$$P = nP_1 R \tag{1}$$

$$P_1 = F_u td\left(2\frac{t}{d} + 1.56\right) \tag{2}$$

$$R = \left(0.535 + \frac{0.467}{\sqrt{n}}\right) \leq 1.0 \tag{3}$$

Where

P	:	Connection strength
n	:	Number of screws in the connection
P_1	:	Strength for a single screw connection
R	:	Reduction factor that accounts for the group effect
F_u	:	Ultimate tensile strength of joined steel sheets
t	:	Thickness of the joined steel sheet s
d	:	Nominal screw diameter
R	:	Group affect factor which is developed from the past study [19]

D. Experimentation

Three specimens of each connection were tested in order to obtain a credible indication of the capacity of each connection type that possibly used as an alternative to the framing CFS construction. Each type connection was tensioned with a torque wrench to that the rate of stress application in the linier elastic region between 1.15 and 11.5 MPa/s. The speed of testing machine was not being increased in order to maintain a stressing rate when specimen begins to yield (seen Figure 5). The screws are designed to fail when the torque exceeds approximately more than the capacity of the profile, which is around 1.25 to 1.50 times the applied torque in the specimens. This parameter complies with the requirements [16, 17].

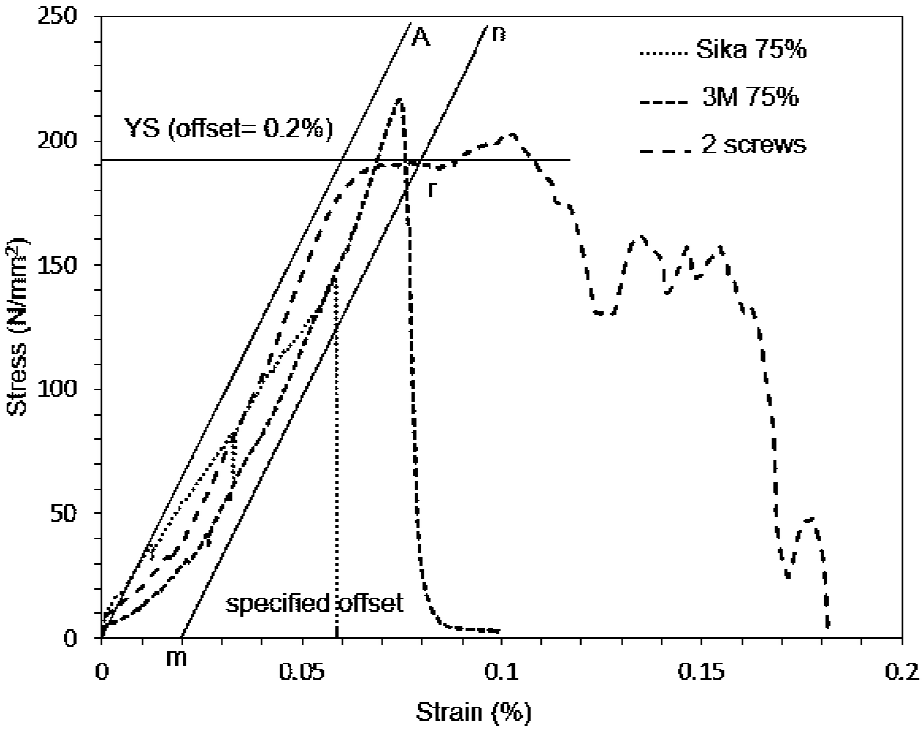
The test set up configuration which is presented in Figure 1 expressing the connection performance. In that test, at the top of griped specimen member two pieces of steel, which were the width of the truss section apart, were attached to the testing machine so that the vertical truss member is being griped to the testing rig. The truss member was well-cut to be able to install in the grip and test machine. It is not recommended that the testing machine is operated in closed-loop control of the force signal through yield [18].

It is necessary to mention that the specimens should be fitted with the testing machine before installing. Also, to fit the specimens inside the testing rig, the griped member of each specimen had to be shortened and dimensioned properly. In addition, the specimens should be in the state of reinforcement so, the lack of testing notes occurred. This reinforcement was particularly important during tension test as it prevented failure of screwed and adhesive connection by spreading the concentrated load throughout the length of the member.

Three specimens of each connection type were conducted statically in tension and another three in static compression. This recommended minimum member of specimens test to be used in capacity testing as recommended [16-17]. The specimens were loaded until failure occurred. The maximum load, as

well as load-extension curve of each specimen, were recorded. Schematic diagram of these specimens is expressed in Figure 5 as one of example from experimental test about the comparison of using 2 screws and 75% adhesive material. In some other point, to enhance the ductility, some method could be considered [20].

Fig. 5. Stress-Strain diagram of the connection of screws and two adhesively connection by the offset method; 2 screws and 75% adhesively bonded connection



Source: own research

In reporting value of each yield strength obtained by this method, the specified value of offset used to be stated in parentheses after the term yield strength. In this case, m line is constructed a parallel to the initial portion of the stress-strain curve but offset by 0.2% from the origin. Line *m r* is drawn at a slope equal to Young's modulus.

E. Experimental Result

A load-extension graph was plotted for each test parameter, and the maximum load capacity of each specimen is reported in Table 4. An example of the load-extension graphs produced for each specimen specifically 2 screws and 75% adhesive material is shown in Figure 4. It should be mentioned that screws

connection offer higher elongation than adhesive connection includes elastic and plastic elongation.

Furthermore, the adhesive connection is only given in elastic scheme, but it is still being considered as an alternative connection that could manage the same function or alternate of screws connection with the higher start point of the strength capacity. The linear part of the curves in adhesive connection is relatively small. That is because the implementation of the adding the coherence to the CFS and it could be effected by the curing method. Hence, the graphs imply the adhesive looseness and sliding as well, which lead to the occurrence of nonlinearity in the graphs.

Contemplating the results, it is clear that the capacity of screws both in tension and compression are slightly different than the strength capacity of both used adhesive. The significant different occurs in the stroke, it is informed in Figure 5.

4. Conclusion and Recommendations

Comparison between the experimental results of the truss connection and the capacities which are calculated indicates that both the adhesive material could easily displace screws connection. It offers nearly typical strength capacity but should be evaluated more about the applied configuration. Hence, the capacities relied upon to provide accurate indications of true capacities. In addition, scrutinizing the experimental results, some recommendations can be made as below.

Sikadur 31 CF Normal connections have obvious lower capacity in both tension and compression compare to both another type of connection used. Therefore, it is not recommended that these connections be used in the CFS construction rather than the common currently used type screws connection. Further, it could be facilitated to propose a combination connection.

3M Scoth-weld DP810 connections have a higher capacity than the Sikadur 31 CF Normal and screws connections in load-maximum capacity which is also considered to be due to the thightening of the CFS member. However, similar to Sikadur 31 CF Normal, the tension, and compression in load-deformation behaviour capacity of this connection is aproximately 9.54 mm that is a half of the screws connection. It is presented in the stress-strain curve about the comparison. This means that elongation currently limits the design of these connections and therefore it would be desirable to be further developed as one of the considered adhesive material for truss framming connetion.

Table 4. Comparison of truss connection capacities screws and adhesive with the failure condition

Specimens	A_n (mm^2)	Average maximum load from test – P_{max} (kN)		Failure Description
		Tension	Compression	
8M 1 screw	24	4.923	4.972	Tilting
8M 2 screws	24	9.125	8.988	Pull-through
8M 3 screws	36	12.525	11.907	Pull-over
50% SIkadur 31 CF Normal	24	5.847	5.440	Popped-off
75% SIkadur 31 CF Normal	24	6.544	6.535	Popped-off
100% SIkadur 31 CF Normal	36	13.368	12.285	Popped-off (loose)
50% 3M Scoth-weld DP810	24	9.121	9.243	Ineffective coherence
75% 3M Scoth-weld DP810	24	10.527	11.917	Tearing failure from truss
100% 3M Scoth-weld DP810	36	14.753	13.737	Coherence

Source: own research

It is noteworthy to mention that the failure mode which was exhibited by the truss connections fastened with screws normally occurs. In some cases, use of screws should be considered by the area of CFS member. The small are of the CFS member could only resist several numbers of screws. It is mentioned that when the strength capacity is needed the total number of screws is increased. Fact, it will affect the failure of its system connection.

However, despite changing the CFS member e.g. the thickness of the CFS itself, the combination connection is proposed as the next issue that should be followed. These modifications no need to require major changes to the materials being used for the currently in use framing system and also would involve

significant increases in load-maximum capacity as well as the load-deformation capacity. It is combined the benefits of adhesive connection and screws connection. In another hand, the cost of the framing materials will have no high impact.

When considering further improvements to the connection capacity in both tension and compression, it must not be forgotten that the working time of adhesively bonded material that may affect the cycle of construction and no standard of adhesive connection for structural elements yet.

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