International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 2
ISSN: 2088-5334

Assessing the Tensile Capacity of Cold-Formed Steel Connections using Self-Drilling Screws and Adhesive Materials

Indra Komara[#], Endah Wahyuni[#], Priyo Suprobo[#], Kıvanç Taşkin[*]

[#]*Civil Engineering Department, Institut Teknologi Sepuluh Nopember, ITS - Sukolilo, Surabaya, 60111, Indonesia*
E-mail: indra12@mhs.ce.its.ac.id, endah@its.ac.id, priyo@its.ac.id

[*]*Civil Engineering Department, Anadolu University, Eskisehir, Turkey*
E-mail: kivanct@anadolu.edu.tr

***Abstract*— This paper presents a review of the proposed design for assessing the tensile capacity of a simply truss framing system of cold-formed steel. A series of connection tests were made to investigate the capacity of connections by its deformation and load caring capacity. Furthermore, Screw connections were compared to adhesive connections. Those were created of 1 screw to 3 installed screw using 8 mm screw. On the other hand, 50%, 75% and 100% percentage of adhesive, i.e., A3M and ASK were also added to be evaluated. As a result, the experimental condition was carried out for developing a model to predict the performance capacity of each specimen. The test specimens are a single lap C connection with one end fixed by a grip, and the other end is tensioned. Each specimen was subjected to the load maximum capacity and the load deformation behaviour. The adhesive material was made of the total area of screw connection which is controlled by the volume of its area. Further, the comparison connection was considered for the analysis of the connection capacity, which was estimated from the specimen's maximum load and the load-deformation behaviour. This research is also considered to face the problem of significant fracture mechanism and used as a further alternative solution. As a result, both adhesive materials could easily displace screw connection. ASK has a lower strength capacity than A3M but implied a better fracture mechanism. It was offered nearly similar behaviour and was suggested to evaluate the behaviour of screw-adhesive connection in advance.**

***Keywords*— cold-formed steel; connection; adhesive; experimental; strength capacity; behaviour**

I. INTRODUCTION

The increase of the recent research and diversity of the commercial application dealing with the usage of cold-formed steel (CFS) structures in Indonesia construction industry 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 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 [1], [2] composed several types of CFS connection.

This paper describes the experiments conducted to develop a new alternative connection and apply it to the roof truss frame system, which could be further evaluated for another various construction system. The performance of the connection is primarily dependent on the number of screws and the use of adhesive material. The first research conducted adhesive connection and self-drilling screw for roof truss connection. It enhances the capacity of the roof truss element and minimizes the fracture of the element [3], [4].

However, the adhesively bonded connection should be examined to understand the connection behaviour by increasing the percentage of adhesive. Different type of adhesive material should be evaluated to know the proper connection. The test series consisted of tension test and connection test. Primarily, the tension test of adhesive and the CFS material has been studied [2]. In addition, the performance of connection by the influence of screws number and adhesive percentage were studied. The cold-formed steel C-section (CFS-CS) is used as a section connection. The maximum number screw, i.e. 1 to 3 screws are considered analogously with the percentage of 3M Scotch-weld DP810 (A3M) and Sikadur 31 CF Normal (ASK), i.e., 50%, 75%, and 100%. The rate of adhesive material is occurred from the total area of screwed connection and controlled by the volume of material. The thickness of the adhesive should not be over 1 mm. Present the material simply and concisely.

Finally, the CFS-CS were tested under continuously tensioned load failure. The load maximum capacity and load-deformation behaviour were investigated. The main factors of the connection test were connection configurations, expressed in Table 4. The fracture mechanism is further studied according to previous research [5]. In the analysis of the CFS-CS connection, the stiffness of the connection derived from the stress-strain curves of the connection test.

A. *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. [6] 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 [7], [8] 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 [9] 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., [10]-[13] and Budiman et al. [14]-[15] 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 [5]. 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 et al. [2]-[4] analysed 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.

II. Material and Method

A. *Section Geometry and Material Properties*

1) Section Geometry: The CFS-CS which was fully made by cold-rolling with the clinching technique, used throughout this study. The flange width and web depth of the CFS-CS were 35 and 75 mm, successively, and the thickness was 1.0 mm. The pitch of clinching on the web was 5 mm in a staggered position. The CFS-CS section geometry is shown in Fig. 1, and the section properties are given in Table 2. The effective area was estimated according to American Iron and Steel Institute (AISI) specifications assuming that the section was under uniform compression [16].

TABLE I
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%

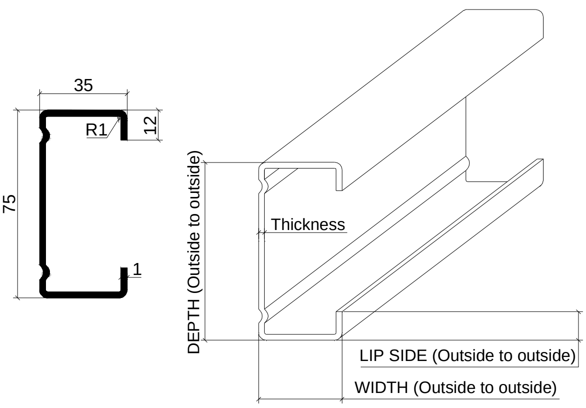

Fig. 1 Section geometry and dimension of CFS section (unit; mm)

2) Material Properties: The structural grade of the CFS-CS was G550. The nominal yield and ultimate strengths were 590 and 600 MPa, respectively. The first test specimens, tensile coupons were cut from the flat area of the CFS-CS sections. Tensile coupon test results are illustrated in Table 3. The experimental yield and ultimate tensile strength were greater than the nominal yield and ultimate tensile strength, in each specific case. However, the final stroke ranged from 16 to 18 mm with the average of 17.43 mm which was lower than the mild steel.

TABLE II
CFS-CS TENSILE COUPON TEST

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

TABLE III
ADHESIVE MATERIAL TENSILE COUPON TEST

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

The diameter of the screws used for joining the CFS-CS was M8-11 Hex washer roof, i.e., 8 mm in the head of screws, and the nominal shear strength capacity was 1.7 kN, which was provided by the manufacturer, expressed in Fig. 3. The length and the grip length were 20 and 12 mm, respectively. Then, for the adhesive material, A3M and ASK were assessed in this study as a material comparison.

The A3M property is based on epoxy adhesive or epoxy glue, low odour adhesive which is ideal for any setting where harsh fumes or flammability are at issue, provides high shear and peel strength and is toughened for impact resistance, illustrated in Table 3, 10 minutes work life and 20 minutes handling strength bonds oily metals with minimal surface prep and bond most metals., this adhesive material is compounded by two components, for instance, illustrated in Fig. 2, A pellucid and B mostly pellucid in grey. The mixed ratio is 1:1 that smelted thill the colour affiliate to dark grey.

The ASK is moisture tolerant, thixotropic, structural two-part adhesive and repair mortar, based on a combination of epoxy resins and special fillers, designed for use at a temperature between +10˚C and +30˚C. As it uses, this type adhesive material could be allocated for several functions such as retrofitting, joint filling and crack-selling or repairing.

B. Experimental Method

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 the adhesive connection. The maximum number of screws in connection is 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.

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 adhesive 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.

The calculation of stress takes the original cross-sectional area of the narrow section into account. The tensile strength (σt) could be calculated using Equation (1).

$$\sigma_t = \frac{F}{A} \tag{1}$$

where
F = Load at failure in N
A = Original cross-sectional area of the specimen (in m^2) at the narrow section

Fig. 2 Adhesive material based on epoxy; (a) 3M scotch-weld DP810, (b) Sikadur 31 CF normal

TABLE IV
SPECIMEN CONFIGURATION

Specimen	Configuration		
	Type 1	**Type 2**	**Type 3**
Sikadur 31 CF Normal	ASK50	ASK75	ASK100
3M Scoth-weld DP810	A3M50	A3M75	A3M100
Screw Connection	S1	S2	S3

where: S = screw, 1,2,3 = number of screw, A = adhesive, SK=Sikadur 31 CF Normal, 3M = 3M scotch-weld DP810, 50, 75, 100 = percentage of adhesive (%)

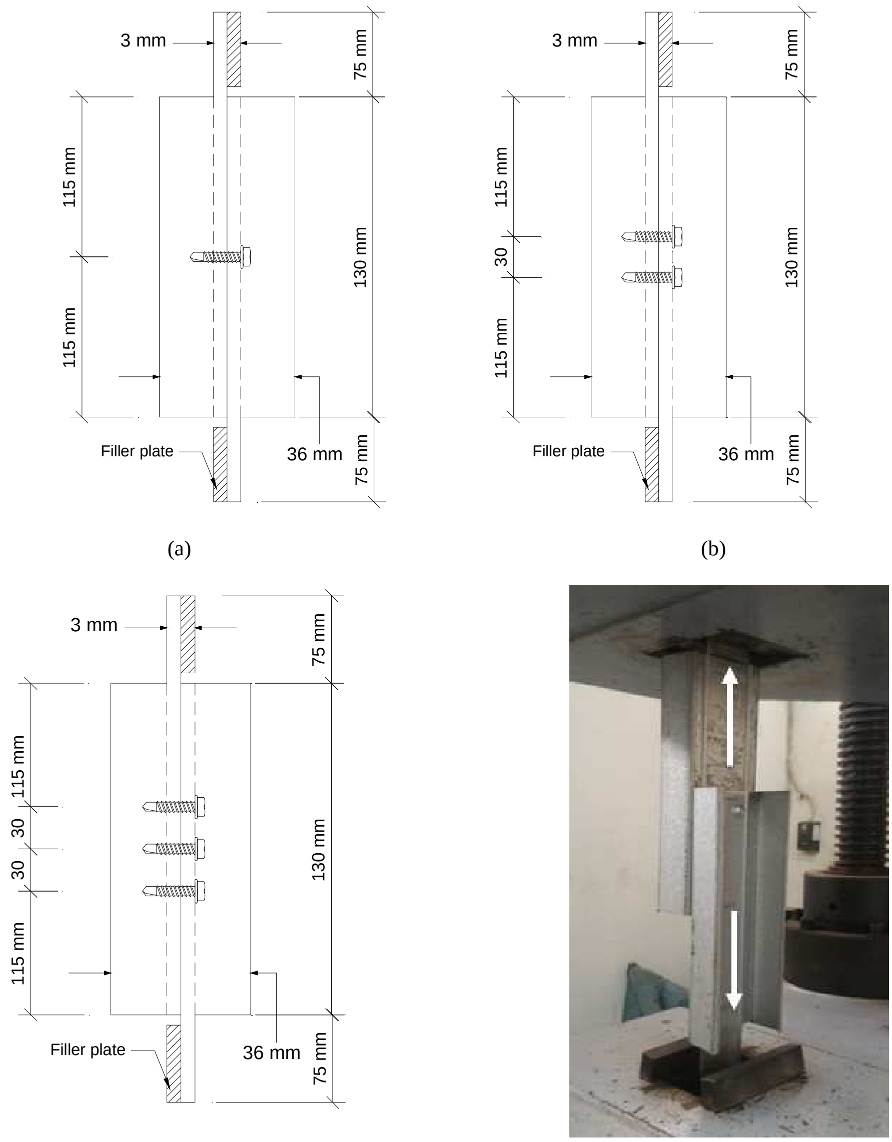

Fig. 3 Overall test set-up evaluating connection capacity

The area can be calculated before the test or after the test by measuring the width and the thickness of the specimen at the expected failure zone.

The adhesive material is inserted into the screw connection by its area. Fact, the volume, and the area are different in each configuration. These considerations are considered to be implicated in various framing connection system. The basic pattern for the design of the CFS-CS members is in accordance with the design code [16-17]. It also assigned a minimum spacing of screw that should be followed. In this analysis, 3d spacing was involved as the minimum screw spacing.

TABLE II
COMPARISON OF TRUSS CAPACITIES SCREW AND ADHESIVE

Specimens	A_n (mm^2)	Average maximum load from test – P_{max} (kN)		Failure Description
		Tension	Compression	
S1	24	4.923	4.972	Tilting
S2	24	9.125	8.988	Pull-through
S3	36	12.525	11.907	Pull-over
ASK50	24	5.847	5.440	Popped-off
ASK75	24	6.544	6.535	Popped-off
ASK100	36	13.368	12.285	Popped-off (loose)
A3M50	24	9.121	9.243	Ineffective coherence
A3M75	24	10.527	11.917	Tear-out failure from truss
A3M100	36	14.753	13.737	Less coherence

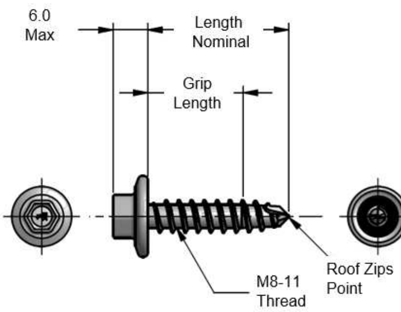

Fig. 4 Screw section detail

Specimen test set up is presented in Fig. 3. 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 3, respectively.

The connection pattern was cantered 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 positions 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.

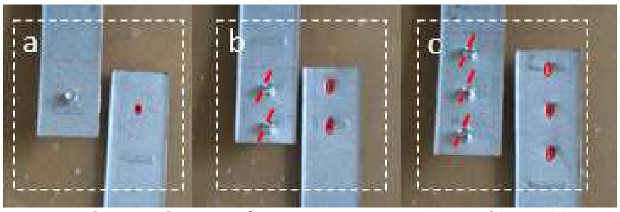

Fig. 5 Failure mechanism of Screw connection; (a) S1, (b) S2, (c) S3

The adhesively material is added as an alternative using Sikadur 31 CF Normal, and 3M Scotch-weld DP810 expressed on Fig. 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 the proposed design of each connection are shown in Table 2.

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 linear 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 Fig. 4). The connection is 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].

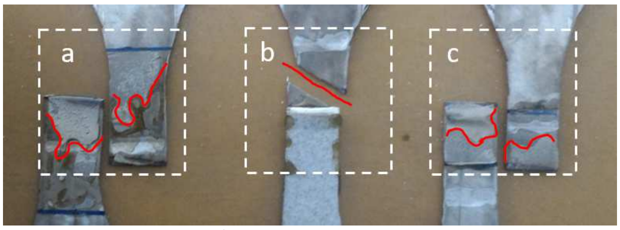

Fig. 6 Failure mechanism of A3M connection; (a) A3M50, (b) A3M75, (c) A3M100

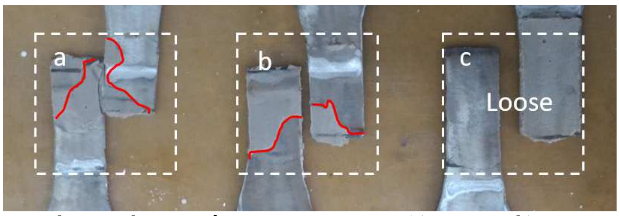

Fig. 7 Failure mechanism of ASK3M connection; (a) ASK50, (b) ASKM75, (c) ASK100

The test set up configuration which is presented in Fig. 4 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.

Illustrated in Fig. 3 above, the connection pooped-off happened in almost all connection condition. It is stated that coherence of ASK should be controlled in advance, especially at the minimum working time which is 20 min later than A3M. 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 Fig. 6. Tearing failure of the section away from the connection occurred at variation 4b. The resemblance of each parameter is performed respectfully in Table 5.

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 [17]-[19]. The specimens were loaded until failure occurred. The maximum load, as well as load-extension curve of each specimen, was recorded. Schematic diagram of these specimens is expressed in Fig. 8 to 10. In some other point, to enhance the ductility, some method could be considered [20]-[22].

III. Result and Discussion

A load-extension graph was plotted for each test parameter, and the maximum load capacity of each specimen is reported in Table 5.

The load-extension graphs produced for each specimen in order as presented in Fig. 8 to 10. It should be mentioned that screws connection offers 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 affected 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.

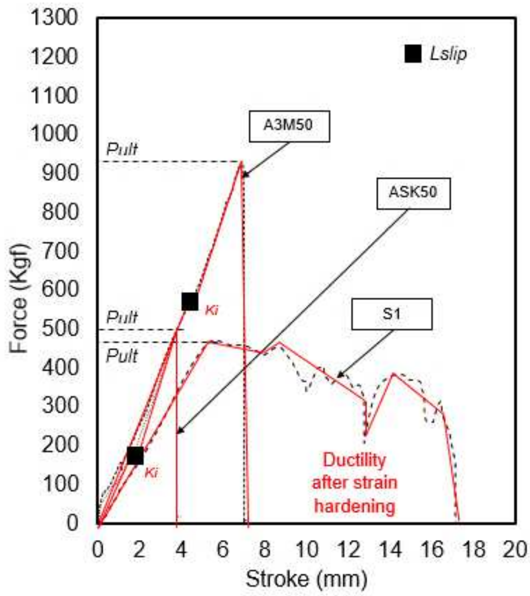

Fig. 8 Stress-strain diagram; S1-A3M50-ASK50

Contemplating the results, it is clear that the capacity of screws both in tension and compression are slightly different from the strength capacity of both used adhesive. The significant difference occurs in the stroke, it is informed in Fig. 10. As information, S1, S2, and S3 showed ductility after strain hardening which are different from the configuration of ASK and A3M with no condition after strain hardening.

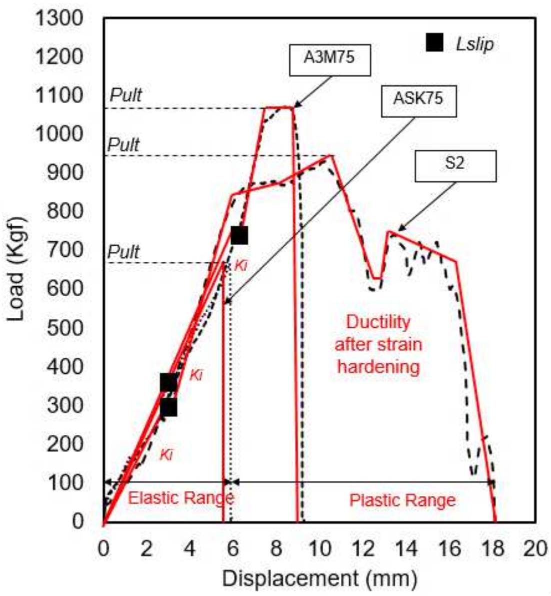

Fig. 9 Stress-strain diagram; S2-A3M75-ASK75

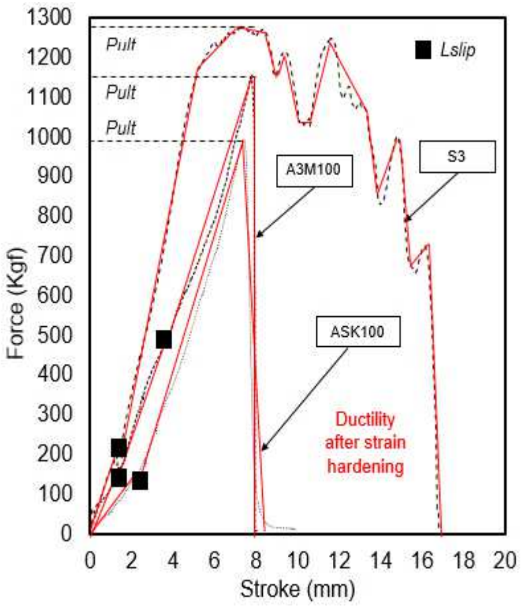

Fig. 10 Stress-strain diagram; S3-A3M100-ASK100

IV. Conclusion

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 to be directly applied in construction. 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.

The ASK 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. This is due to few studies about the function of adhesive material especially affected by ambient temperature. Further, it could be facilitated to propose a combination connection.

The A3M connections have a higher capacity than the ASK and screws connections in load-maximum capacity which is also considered to be due to the tightening of the CFS member. However, similar to ASK, the tension, and compression in load-deformation behaviour capacity of this connection is approximately 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 framing connection.

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 area 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.

Acknowledgment

The research for this paper was financially supported by the Indonesian Research Grant, funded by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia.

References

[1] Serrette, R.., and Peyton, ,. Strength of screw connection in cold-formed steel construction. Journal of structural engineering, 135 (8), 951-958, 2009.

[2] Komara, I., Taşkin, K., Wahyuni, E., Suprobo, P, Adhesively Bonded Connection and Screw Connection of Single Truss Cold-Formed Steel Canals Frames Due to Tensile Test Behavior, Proc. ICOCEE17, 2017.

[3] Anwar, S.N.R., Suprobo, P. and Wahyuni, E, Axial and flexural performance of adhesive connection on cold-formed steel structure. International Journal of Technology, 4, 699-708, 2015.

[4] Anwar SNR, Wahyuni E, Suprobo P, Tensile performance of adhesive joint on the cold-formed steel structure. International Journal of Engineering Trend and Technology, 10, 5, 2014.

[5] Serrette, R., and Peyton, D, Strength of screw connection in cold-formed steel construction. Journal of structural engineering, 135 (8), 951-958, doi: 10.1061/ASCE0733-9445. 2009.

[6] C.A. Rogers, G.J. Hancock, Screwed connection tests of thin G550 and G300 sheet steels, J. Struct. Eng. 125 p. 128, 1999.

[7] Young B., Chen J, Column Tests of Cold-Formed Steel Non-Symmetric Lipped Angle Sections, Journal of Constructional Steel Research, Vol. 64, p.808-815, 2008.

[8] Peköz, T, “Design of cold-formed steel screw connections”, Proc., 10th Int. Specialty Conf. on Cold-Formed Steel Structures, Univ. of Missouri-Rolla, Rolla, St. Louis. 1990.

[9] Young, B. and Yan J, Channel Columns Undergoing Local, Distortional, and Overall Buckling, ASCE Journal of Structural Engineering, 128(6), 728-736, 2002.

[10] Wahyuni, E., Raka, I.G.P., Budiman, E, Structural behavior submerged floating tunnels with different cables configurations under environmental loading. Dinamika teknik sipil, Vol. 11, No.3, pp. 212-215, 2011.

[11] Wahyuni, E., Istiono, H., Iranata, Data., Komara, I., Non-linier Analysis of failure mechanism of steel truss bridge. ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 24, pp. 14373-14382, 2016.

[12] Wahyuni, E., Suswanto, B., Komara, I. Effect of angle of inclination cables on the performance of submerged floating tunnel under hydrodynamic load. The 5th ETMC, Vol. 5, No.GC/015, pp. 3-11, 2015.

[13] Wahyuni, E., Komara, I. Evaluation of Buoyancy Weight Ratio in Submerged Floating Tunnel Under Hydrodynamic Loads. A Case Study of Seribu Islands. IABSE conference Guangzhou, Proceedings, pp. 938-945, 2016.

[14] Budiman, E., Suswanto, B., Wahyuni, E., Raka, I.G.P. Experiments on snap force in tethers of submerged floating tunnel under hydrodynamic loads in case of shallow water. ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 24, pp. 14383-14390, 2016.

[15] Budiman, E., Wahyuni, E., Raka, I.G.P., Suswanto, B. Conceptual study of submarine pipeline using submerged floating tunnel. ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 9, pp. 5842-5846, 2016.

[16] AISI S100. North American Spesification fot the design of Cold-Formed Steel Structural Members. American Iron and Steel Institute and Canadian Standards Association. 2007.

[17] AS/NZS, Cold-Formed Steel structure. Standards Australia and The Australian Institute of Steel Construction, 1996.

[18] ASTM E8/E8M-09. Standard test methods for tension testing of metallic material. American Society for Testing and Materials, 2010.

[19] LaBoube R.A., Sokol M.A. Behavior of screw connections in residential construction. Journal of structural engineering, Vol. 128(1), p. 115-118, 2002.

[20] Haydarolu C, Taskin K and Celik O.C. Ductility enhancement of round HSS Braces using CFRP sheet wrap. Proc. Eurosteel 2011, Budapest, Hungary, 2011.

[21] Komara I, Wahyuni E, Suprobo P. “A study on Cold-formed Steel Frame Connection: A review”, IPTEK The journal for technology and science, Vol. 28, No.3, pp. 83-89, 2017.

[22] Komara I, Taskin K, Wahyuni E, Suprobo P, “The experimental study of cold-formed steel truss connections capacity: Screw and adhesive material,” Journal of current construction issue, Vol. 3, No. 2, pp. 229-24,. 2017.