JSMBE

JOURNAL OF STRUCTURAL MONITORING AND BUILT ENVIRONMENT
e-ISSN: 2821-3432

Vol. 6 No. 1 (2026) 43-48
https://publisher.uthm.edu.my/ojs/index.php/jsmbe

Tensile Performance of Box-Sleeve Cold Formed Steel Connection

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DOI: https://doi.org/10.30880/jsmbe.2026.06.01.006

Article Info

Received: 20 January 2026
Accepted: 2 May 2026
Available online: 30 June 2026

Keywords

OPEFB fibres, hot water treatment, tensile strength, hydration rate, shear capacity, cold formed steel, stirrup, Response2000

Abstract

This study focused on the box-sleeve connection in the flange section of cold-formed steel C-sections. The research addressed the limited use of cold-formed steel compared to hot-rolled steel, emphasizing the need to study its tensile strength. The objective was to determine the tensile strength of box-sleeve connections with self-tapping screws and to analyze failure modes. Twelve samples were tested, divided into two thicknesses (0.75 mm and 1.00 mm), with each thickness having six samples. Three samples per thickness used two screws, while the other three used four screws. Tensile tests measured the ultimate load for each configuration. For the 0.75 mm thickness, the average ultimate load was 6–8 kN with two screws and 12–14 kN with four screws. For the 1.00 mm thickness, the average ultimate load was 12–14 kN with two screws and 20–25 kN with four screws. The results showed similar performance between 0.75 mm with four screws and 1.00 mm with two screws. The study concluded that both thickness and the number of screws significantly influence the tensile strength of the connection.

1. Introduction

The introduction of cold-formed steel (CFS) in box sleeve connections, specifically when utilizing self-tapping screws, has garnered considerable attention in structural engineering due to its potential to enhance tensile strength and efficiency in assembly. Cold-formed steel is a versatile material that undergoes a process of cold working to produce thin-walled steel sections, which are then used in various structural applications, including box sleeve connections. CFS members are created by coldforming thin steel sheets or strips into different cross-sectional shapes such as C-sections, Z-sections and hat sections (1). These connections are commonly used in the construction of steel structures, where they are designed to transmit loads and resist deformations, particularly in tensile applications.

Physical elements that was focused on the site of binding action and mechanically binding structural parts are known as connections (2).Bolts, screws, blind rivets or cartridge fired pins are commonly used in joints between cold-formed sections or for steel sheet connections (4). The self-tapping screws are employed in box sleeve connections, they offer several advantages. Self-tapping screws are capable of creating their own threads as they are driven into the material, which reduces the need for pre-threaded holes and speeds up the assembly process. This, in turn, improves the overall efficiency and cost-effectiveness of the construction process while still providing strong, reliable joints. In terms of tensile strength, the combination of cold-formed steel and self-tapping screws can provide a highly resilient connection, capable of withstanding significant loads without failure. The

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mechanical properties of cold-formed steel, coupled with the precise placement and engagement of self-tapping screws, lead to a highly durable connection that is wellsuited for various structural applications.

In box sleeve connections, a C-section's flanged region is typically reinforced by the sleeve, which serves as a conduit for load transfer. This configuration is especially advantageous when the primary concern is maximizing tensile strength. The tensile behavior of cold-formed steel in this context is significantly influenced by factors such as the material's thickness, the geometry of the connection, and the type of fasteners used. Self-tapping screws, which create their own threads when inserted into the steel, are commonly employed due to their high holding capacity and quick installation.

Studies have shown that the use of self-tapping screws in cold-formed steel connections can provide reliable performance under tensile loads. The screws' ability to penetrate the steel without pre-drilling helps achieve a strong bond, which is crucial for ensuring the connection's integrity under tension. Furthermore, the cold-formed steel's ductility and the interaction between the screw and the material contribute to the overall tensile strength of the connection. Studies have demonstrated that the tensile strength of box sleeve connections using cold-formed steel and self-tapping screws can be significantly enhanced compared to traditional connection methods, making them a promising choice for modern construction practices (3).

2. Methodology

This study aims to determine the tensile performance of box-sleeve cold formed steel connection with self-tapping screws and to determine the tensile strength with different thickness and number of screws. The sample of the box-sleeve connection were connected with self-tapping screws in each thickness with number of screws connected. The C section of cold formed steel were cut and connect with screws into box connection. Each sample was divided into 2 thickness and each thickness were connected into 2 or 4 number of screws. The total sample of the connection was 12 sample and each 6 sample of the thickness of 0.75mm and 1.00mm. The sample were cut into 250mm and 250mm for each leg. Then, another 200mm sample were cut to connect the leg sample. The sample were connect with different number of screws which is 2 number of screws and 4 number of screws in each flanged. The distance for the screws are followed with AISI standard. The tensile testing were conducted to determine the yield strength and the ultimate load capacity. Testing were test using 120kN Universal Testing Machine. Then the result were compared with the tensile resistance formula in Eurocode 1-1-3. All the data were collected into spreadsheet and the graph was plotted based on the data.

2.1 Sample Preparation

Before tensile testing, sample preparation were conducted which is the sample were cut into pieces before combine into a sample. This sample were divided into 2 different thickness which is 0.75mm and 1.00mm. For each thickness, the sample were connected with 2 different number of screws. 6 sample were prepared for each thickness and each thickness were divided into 3 sample in different number of screws. Table 1 below show the sample prepared and the number of screws for each sample.

Table 1 *Sample preparation*

Sample Thickness (mm)	Number of screws	Number of samplings	Sample label
0.75	2	3	1-BS075-2, 2-BS075-2, 3-BS075-2
	4	3	1-BS075-4, 2-BS075-4, 3-BS075-4
1.00	2	3	1-BS100-2, 2-BS100-2, 3-BS100-2
	4	3	1-BS100-4, 2-BS100-4, 3-BS100-4

2.2 Tensile Resistance

Tensile strength for the CFS were calculated based on the Eurocode 1993-1-3, and this calculation were taken to determine the axial tension for the CFS. Based on the Eurocode, some factor was taken into the formula to fine the tensile resistant for the CFS. This formula shows the criteria were needed to determine the resistant.

$$\mathrm{NtRd} = \frac{\mathrm{fya\ Ag}}{\gamma \mathrm{Mo}} \tag{1}$$

Where:
Ag is the gross area of cross-section
Fnrd is the net-section resistant from type of fastener
Fya is the average yield strength

2.3 Shear Resistance

Shear Resistance Shear resistance of the CFS were taken to determine the maximum shear stress that can be applied at the CFS. The shear resistance can be calculated according to Eurocode EC3 1993-1-3. The calculation can be used to find the allowable shear that can be afford due to the stress.

$$\mathrm{VbRd} = \frac{\frac{\mathrm{hw}}{\sin\emptyset}\ \mathrm{tfbv}}{\gamma \mathrm{Mo}} \tag{2}$$

Where :
Fbv is the shear strength considering buckling
Hw is the web height between the midlines of flanges
Ø is the slope of the web relative to the flanges

2.4 Bearing Resistance

The bearing resistance are taken from the connection of the screw with the CFS. The bearing capacity of the screw are taken to determine the maximum value of the resistance of the screw and the CFS. Other than that, the bearing resistance required to make sure the displacement of the CFS. This formula were used to find the bearing according to EC.

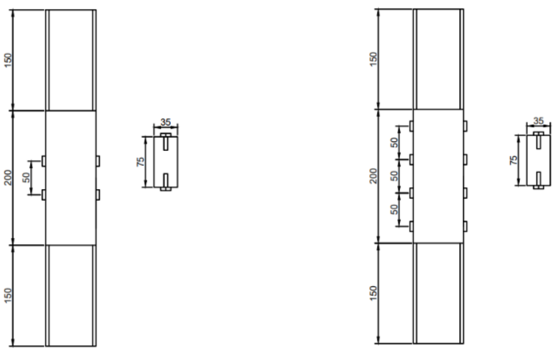
$$\mathrm{Fbrd} = \frac{\alpha\ \mathrm{fu\ dt}}{\gamma \mathrm{M2}} \tag{3}$$

$\alpha = 3.6\sqrt{t/d}$, if $t = t_1$

The result of the bearing capacity was taken to determine the allowable number of screw that can holds the CFS.

3. Sample Testing

Figure below shows the arrangement of the sample before the experiment were carry out. The sample need to be located vertical from the machine. The sample are placed on the middle of the machine than it stretches until the it failure.



(a) **(b)**

Fig. 1 *Sample arrangement (a) 2 Number of screws; (b) 4 Number of screws*

To start the tensile test, the sample were placed on the UTM machine and the sample were stretch out until it fails. The placement of the sample are as the figure below.

Fig. 2 *Sample placement at UTM machine*

4. Finding and Discussion

The parameter of the displacement and load capacity were obtained from the UTM machine. Based on the data, spreadsheet of the result were produced and the correlation between displacement and load were drawn based on the data given.

4.1 Tensile Resistance

Tensile resistance for analytical are consider by calculated based on the Eurocode 3. The gross area for the sample were based on the thickness and the area that are connected.

Thickness 0.75mm

$$\frac{(360 \times 103)(75 \times 100)}{1.0} = 2.7\ kN$$

Thickness 1.00mm

$$\frac{(360 \times 103)(100 \times 100)}{1.0} = 3.6kN$$

4.2 Tensile Performance

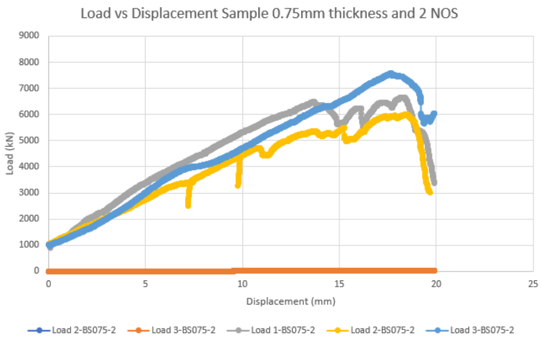
The tensile test were conducting on 12 sample of box-sleeve cold formed connection on the flanged connection. This sample have 2 different thickness and each thickness has three connected with 2 number of screw and 4 number of screws connected at the flanged section. After conducting the tensile testing, it shows the graph of each ultimate strength and the lower yield strength and the maximum yield strength (5). Based on the testing, Table 2 and shows all the results of the maximum strength and the yield strength of the tensile test

The Table 2 explains that the lower yield strength formed and the 2 number of screws explain that the yield scores between 4kN and 5kN strength but the 4 number of screws shows increase of the strength between 5kN and 6kN. This shows that the number of screws affect the strength of the tensile performance between the connection. Although the thickness of 0.75mm are stronger that with affect from number of screws, the different thickness with lower number of screws match up and increase a little of the strength. The strength of the 1.00mm are the same at 0.75mm thickness with different number of screws.

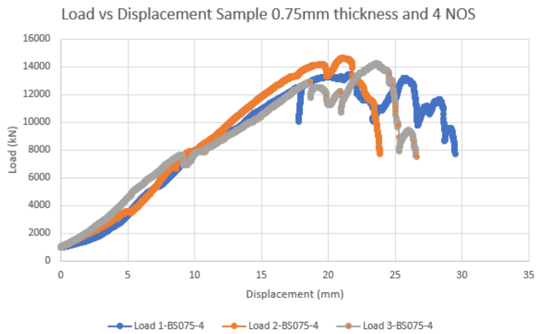
Table 2 *Results of the maximum strength and the yield strength of the tensile test*

Number sample	Lower yield strength (kN)	Ultimate load capacity (kN)
1-BS075-2	3.5	6
2-BS075-2	4	6.5
3-BS075-2	3.4	7.5
1-BS075-4	7.9	13
2-BS075-4	8	14.3
3-BS075-4	6	14
1-BS100-2	8	12.5
2-BS100-2	7.7	13
3-BS100-2	8.3	12
1-BS100-4	16.2	25
2-BS100-4	19.3	25.1
3-BS100-4	12.5	22.5

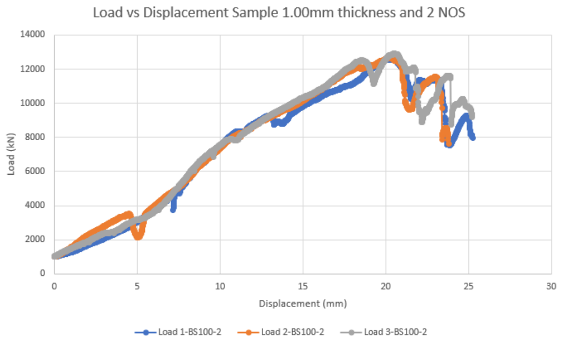
Based on next the figure that shows the different of the maximum load that each sample of thickness 1.00mm with different number of screws can handle. The figure below explains that the ultimate strength of the box-sleeve cold formed connection was concluded by the number of the screws connected and the thickness of the CFS. This strength was compared based on the analytical calculation and those result shows the strength are compatible with the strength. Figure below shows all the combination sample based on the strength. The figure shows more number of screws as more tensile strength and the comparison for 4 number of screw with thickness 0.75mm and 2 number of screws with thickness of 1.0mm are statiscally even or highly same. This shows reduce cost can be consider to making a structure.



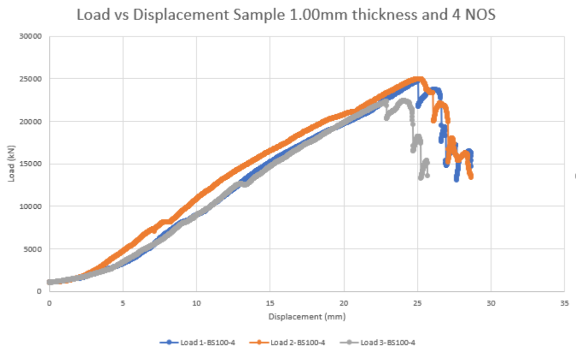
(a)



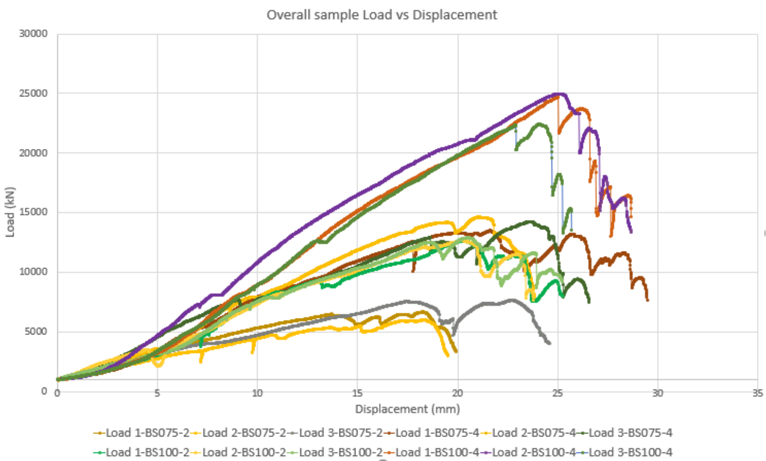
(b)



(c)



(d)



(e)

Fig. 3 *(a) Graph tensile for thickness 0.75mm with 2 number of screws; (b) Graph tensile for thickness 0.75mm with 4 number of screws; (c) Graph tensile for thickness 1.00mm with 2 number of screws; (d) Graph tensile for thickness 1.00mm with 4 number of screws; (e) Graph tensile result for all sample combine*

5. Conclusion

The study successfully achieved its objectives by demonstrating the relationship between material thickness, screw quantity, and tensile performance. It was concluded that increasing the thickness of the CFS and the number of screws significantly enhances the tensile strength and load-bearing capacity of box-sleeve connections. The use of 1.00 mm thick CFS with four screws was identified as the most effective configuration, combining high strength and stability. The analysis also highlighted the critical role of failure modes in determining the reliability of these connections. Screw tilting and shearing underscore the need for precise screw alignment and robust material selection to prevent premature failure. These findings provide valuable insights for the design and construction of CFS structures, emphasizing the importance of optimizing connection configurations to improve safety, efficiency, and cost-effectiveness. Future research could further explore the dynamic behavior of such connections under cyclic loading and environmental conditions to enhance their applicability in modern construction.

Acknowledgement

The authors acknowledge the support from Universiti, Tun Hussein Onn Malaysia throughout this project.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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