

BEHAVIOUR OF SELF-DRILLING SCREW UPON SINGLE SHEAR LOADING ON COLD FORMED STEEL

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Abstract: Self-drilling screws is not the fastener of choice when fastening connections between cold-formed steel sections. A better understanding about self-drilling screws; also known as Tek-screws; is needed in order to develop more optimum connection designs. A study has been performed with the aim of developing a better perspective of the performance of single-shear connections using self-drilling screws in cold-formed steel. The main focus of the study was on several design parameters such as fasteners patterns, screw spacing, and the number of screws in a connection to establish their influence on connection strength.

Keywords: *Self-drilling screw, single shear, cold-formed steel*

1.0 Introduction

The construction industry is looking for ways to cut down the weight of material to enhance the high intensity level of structural performance and cost saving among others and the most effective ways to reduce a material weight is to use lightweight materials such as cold formed steel (Lee *et al.*, 2006; Bong and Osman, 2015). Self-drilling screw is a type of fastener with the ability to drill its own hole and make its own thread when driven into steel sheet using a screw gun. A study has been conducted to gain knowledge as to the performance of single-shear connections using self-drilling screws in cold-formed steel. The main focus of the study was on connection design parameters such as fasteners patterns, screw spacing, and the number of screws used in a connection. This will provide information about whether the parameters will affect the strength behavior of the connection itself. The objectives of the study are to investigate whether different screw configuration patterns affect the connection strength and to study the relationship on strength between the factor of screw increasing and number of screws used in a connection.

The scope of the study includes the investigation on the types of failure that occur on tek-screw connection in a simple shear test. The study will focus only on the shear type of failure. Therefore, the collection of data and information related to this case were compiled including direct shear strength, tensile strength of the steel plate, screw bearing strength, and the connector tilting properties. The usage of self-drilling screws in Malaysia is not as popular as its other counterparts such as bolts and rivet. Detailed information on its behaviour is scarce since the screw itself is an on-going research material. Hence, the research on behaviour of self-drilling screw upon single shear loading on cold formed steel is needed and will also provide a platform for further research. In this research two test were conducted, which were direct shear test on various configuration of self-drilling screw and tensile test of cold-formed steel plates that were used in the shear test. For this study, comparisons were made based on previous research by LaBoube and Sokol (2002). The main comparisons were the effect of configuration pattern and the effect of number of screws. These two factors were related to connection strength of the samples tested.

2.0 Literature Review

A screw is a type of fastener with helical ridge known as thread revolving around the cylindrical part. The difference between screws and bolts is that screws do not need a nut as a fastener. The screw head comes in a variety of design. Self-drilling screw is made from high strength steel with the ability to drill its own thread with its own unique method of installation.

When the number of screws provided is adequate, a single shear connection will fail due to the fracturing of the steel sheets. Previous studies by Laboube and Sokol (2002) shows that the fracture will almost always occur in the steel sheet that has the screw thread exposed, rather than the one against the screw head. If there were several rows of screws, fracturing will occur through the row closest to the jaw of the testing machine.

Based on the same study, Laboube and Sokol (2002) proposed a “Group Effect”. The “Group Effect” is the decrease of the strength per screw when there is an increase in the number of screws; as the screw size and sheet thickness remains constant. The group effect can be defined as the strength per screw for a given connection divided by the connection strength per single screw with the same sheet thickness and screw size. If all screws in a connection acted and contributed equally, the group effect would be 1.0.

Based on their findings, Laboube and Sokol (2002) has derived these three equations that can be used to calculate of the bearing and tilting connection strength based on the strength of a single screw.

$$P = nP_sR \quad (1)$$

Where P = connection strength; n = number of screws in the connection; P_1 = strength for a single screw connection; and R = reduction factor that accounts for the ‘‘Group Effect’’. The equation for P_1 is given by Eq. (2)

$$P_1 = F_u t d (2.0 \frac{t}{d} + 1.56) \quad (2)$$

Where F_u = ultimate tensile strength of steel sheets being joined; t = thickness of the steel sheet being joined; and d = nominal screw diameter. The R factor represents the Group Effect developed from the test results. This effect can be represented by Eq. (3)

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

The design equation is limited to the following range of test parameters: $0.76\text{mm} < t < 1.35$ mm, where t = steel sheet thickness; $4.19\text{mm} < d < 5.46$ mm, where d = outer diameter of screw threads; $s > 3d$, where s = center-to-center screw spacing; 347 MPa $< F_u < 482$ MPa; and $1.19 < F_u / F_y < 1.62$.

3.0 Research Methodology

3.1 Test Parameter

For the design process of the sample, an early hypotheses for test parameters were derived, which were:

- i. Types of failure that will occur rely on bearing strength capacity of the cold formed steel plates (Roger and Hancock, 1998).
- ii. The type of connection test is single shear connection.
- iii. The size of Teks screw used in the experiment was 5.5mm or #12, with design strength $P_y = 450$ N/mm².
- iv. The properties of the connection plates used in the experiment was grade G450 in with design strength $P_y = 450$ N/mm² with thickness of 2.5mm.
- v. Shear strength of individual fasteners can be assumed to be equal if the material thickness is less or equivalent to 4 mm. (refer to BS 5950:1998 (1998); clause 8.1.7)

Several types of failure were expected to occur, such as end tear-out failure, bearing failure, net-section failure, and screw shear failure. AISI (1996) specifies a minimum of

3d spacing. Minimum edge distances 1.5d transversely and 3d longitudinally were also used.

3.2 Test Setup

The general test setup is as shown in Fig. 1. For longitudinal and transverse edge spacing of screws, section E3.1 of the AISI (1996) was referred to.

On the steel sheet, the screw pattern was centred transversely; with the first row of screws located on the minimum longitudinal edge distance from the edge of the sheet. The minimum transverse edge distance was always met or exceeded.

3.3 Test Specimen Details

In this study, the sample have been designed and checked according to several design parameters; which were the checking of end distance and spacing between screws, screw shear strength in tilting and bearing, gross yielding failure check, design-bearing capacity check and end tear out check. These checking were done on the sample for direct shear test. For the tensile test, the sample was designed based on standards provided by ASTM E8/E8M-11 (2011). Fig. 2 and Fig. 3 shows the sample's dimension for the shear and tensile test respectively.

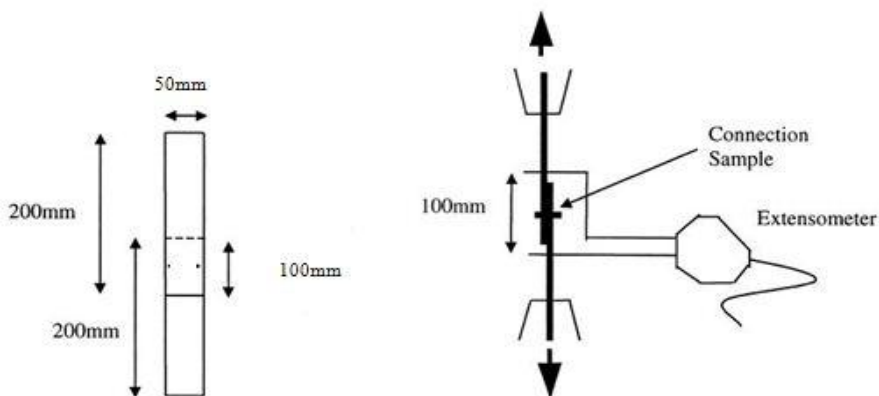


Fig. 1. Test setup for simple shear test

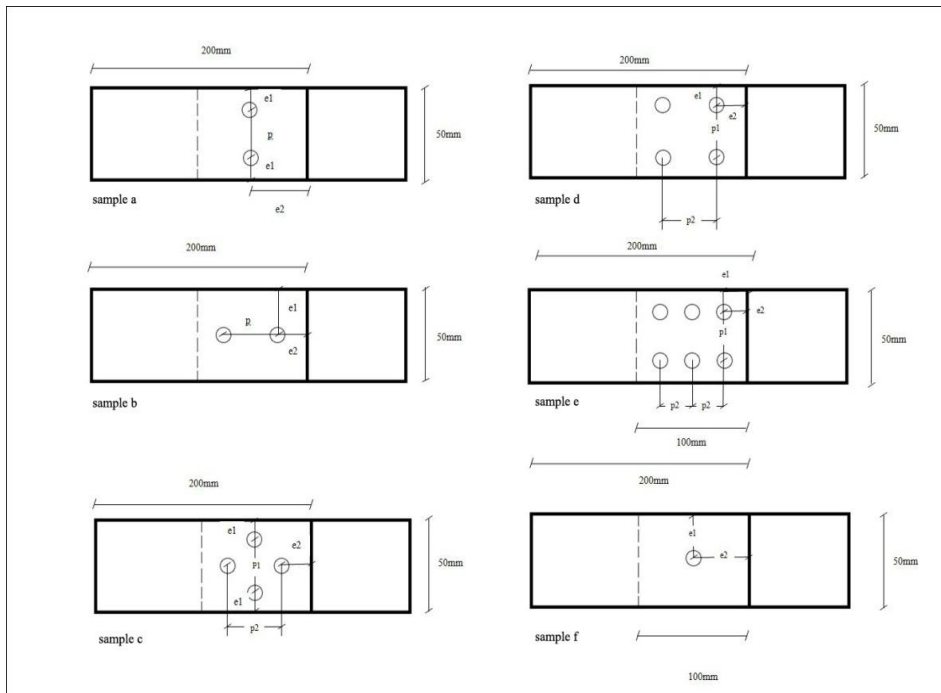


Fig. 2: Direct Shear Test samples dimension

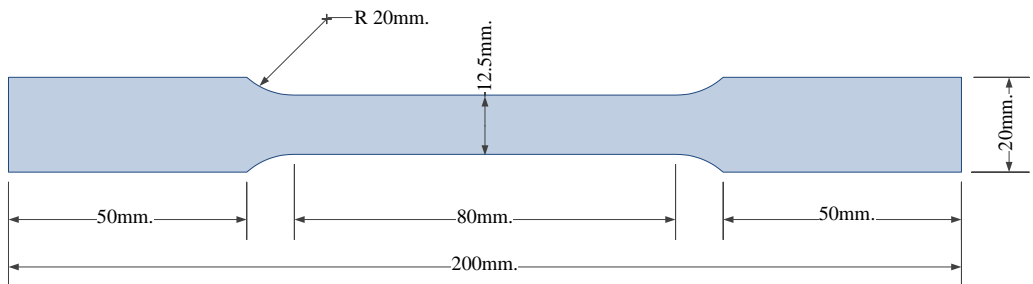


Fig. 3: Tensile test sample dimension

4.0 Experimental Results

Six samples for Direct Shear Test and 3 samples for Tensile Test have been tested and analyzed. Table 1 shows the result of the tensile test. Based on Table 1, the average ultimate design strength for the steel plate was 637.6 N/mm^2 ; the average yield strength was 547.6 N/mm^2 , while the average elongation for all three samples was 25.07%. From the result, it is obvious that there are differences between the two data of steel design strength from the manufacturer, which was 450 N/mm^2 and ultimate design strength, P_u .

Comparisons have been made between this study and previous one done by LaBoube and Sokol (2002). There are two key aspects that have been compared which were the effect of configuration pattern and the effect of numbers of screws.

4.1 Effect of Configuration Patterns

LaBoube and Sokol (2002) came to a conclusion that varying the screw pattern did not significantly vary the strength of connection. However they also concluded that the more rows of screws in connection pattern, the higher the strength of a connection. A row can be defined as a line of screws crosswise to the direction of loading. Table 2 shows the result of four screw pattern tests proving the conclusion that has been made.

As shown in Table 3 below, the pattern of the data is quite similar to the precedent study. Sample F, with connection strength of 9.31kN is a single screw connection which will be the basis of comparison for the value of strength per screw for other types of configuration.

Table 1: Steel plate sample properties

Specimen	Thickness(mm)	P_u (N/mm ²)	P_y (N/mm ²)	Elongation (%)
T1	2.0	640	550	25.4
T2	2.0	637.6	545.2	24.5
T3	2.0	635.2	547.6	25.3

Table 2: Results for Four Screw Pattern Test

Pattern	Connection strength (N)	Connection strength per screw (N)	Group effect
4C	6,639	1,660	0.71
4A	6,702	1,678	0.72
4A	6,782	1,695	0.72
4B	6,938	1,736	0.74
4B	6,955	1,740	0.74
4E	7,044	1,762	0.75
4D	7,400	1,851	0.79

Note: Specimen: 0.76 mm sheets, No. 8 screw, 3d spacing. Single screw connection strength= 2,343 N.

Table 3: results for pattern of multiple screw configurations

Specimen	Connection Strength (kN)	Connection strength per Screw (kN)	Group Effect
A	16.56	8.28	0.89
B	8.94	4.47	0.48
C	34.95	8.74	0.94
D	32.88	8.22	0.88
E	39.44	6.57	0.71

Based on Table 3, the average value for Group Effect is 0.78 which is similar to the precedent study which in the order of around $\pm 7\%$. This shows that the variation of screw pattern did not significantly vary the strength of connection. But, the initial hypotheses the more rows of screws in connection pattern, the higher the strength of connection is shown to be plausible by comparing between samples A and B and sample C and D. Both samples A and C have a screw more aligned in a row when compared to samples B and D.

4.2 Effect of Number of Screws

Standard assumption in design practice assumes that, if a connection has four screws, it will be four times as strong as a single screw connection; as long as the joined sheets did not reach fracture first.

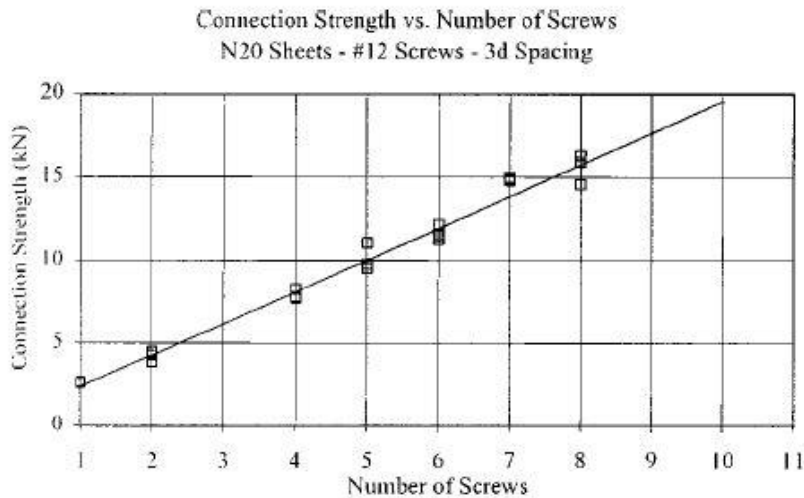


Fig.4: Connection Strength vs Number of Screws

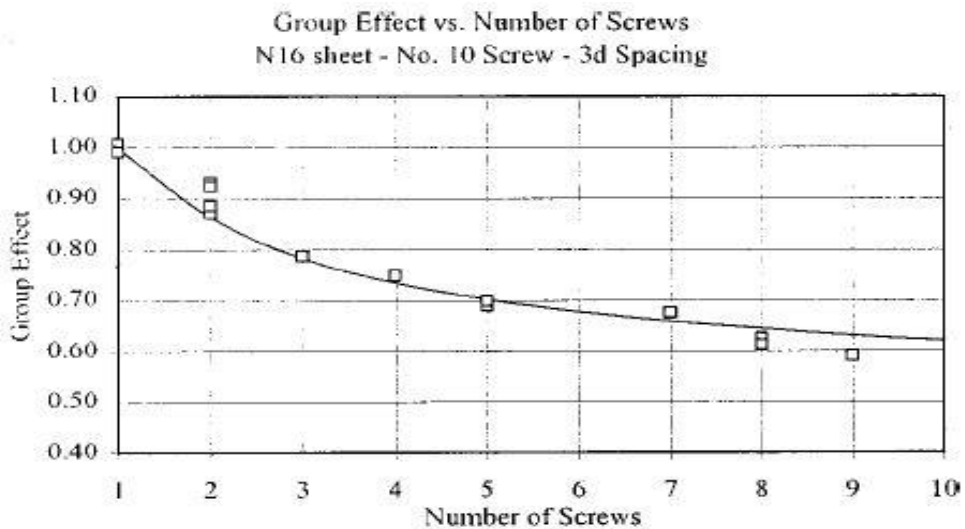


Fig.5: Group Effects vs Number of Screws

LaBoube and Sokol (2002) concluded that the strength per screw in a connection is reduced as the number of screws is increased. This is supported by the analysis plotted in Fig. 4 which shows the graph of connection strength vs. number of screws. Fig 4 shows the graph of Group Effect vs. Number of Screws also support this statement that the strength per screw diminishes as the number of screw increases.

Based on the graphs of Group Effect vs. Number of Screws as in Fig. 4 and Connection Strength vs. Number of Screws as in Fig. 5 has the similar data distribution pattern as the precedent study. Referring to Fig.4, a declining pattern can be observed which confirms that strength per screw will decrease as the number of screws in a connection increases. While Fig. 5 shows that strength per screw for each pattern of configuration is lower than the strength of single screw connection.

5.0 Conclusion

Based on the results obtained from the experiment, all of the study's objectives have been addressed and a better understanding of the behaviour of connections between cold-formed steel with self-drilling screw as fasteners was acquired. The findings of the study conclude that the screw configuration pattern did affect the strength of the connection but not drastically. Strength per screw in a connection decreased proportionally with the increasing numbers of screws. The results of the experiments also showed plenty of similarities with the previous study done by LaBoube and Sokol (2002). Therefore, the formula derived by them is applicable but needs further research to determine the proper universal constant so that it can be used in wider range of test parameters.

Notation

The following symbols are used in this paper:

d = nominal diameter of screw threads

P_u = ultimate steel design strength

P_y = yield strength

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