TENSILE STRENGTH BEHVIOUR OF BOLTED & SCREWED CONNECTIONS OF THIN STEEL SHEET AT ELEVATED TEMPERATURE

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ABSTRACT
Thin profiled steel sheets are commonly connected to the underlying purlins or steel trusses/frame by drilling or tapping of screws and bolts. Fire resistance is quite important for thin steel structures due to the fact that the material properties of structural steel become sensitive when temperature exceeds approximately 400ºC. The objective of this research to investigate the structural behaviour of screw and botted connection of thin profiled steel sheet after elevated temperature. A total of 108 connection coupon test including 48 connected specimens at high temperature tensile tests were conducted to investigate the material deterioration of the thin profiled sheet steels at elevated temperature. A series of test was conducted for bolts and screw connections in form of single and double shear conditions of thin profiled sheet steels from 25 ºC to 1250ºC temperatures. The investigation was also varied in bolt size, screw size, bolt arrangement, screw arrangements and 7 different temperatures. The failure modes and ultimate strength of shear of bolted and screwed connections of thin profiled sheet steels after elevated temperatures are presented. Based on the test results, it was found that the material properties of the profiled steel sheets were found to deteriorate and bolted is better than screwed connections after elevated temperatures. The comparison between the deterioration of the tested connection strengths and that of the material properties at elevated temperatures showed a similar tendency of reduction.

Keywords: Bolted and screw connection; elevated temperatures; failure modes; thin sheet steel; ultimate strength

INTRODUCTION
Bolted and screwed are two conventional connection types which are widely used in light gauge and thin steel structures as shown in Fig. 1. Makelainen and Miller (1983) carried out tensile tests of cold-formed galvanized sheet steel Z33 at elevated temperatures using transient state and steady state methods. Behviour of bolted and screwed connections have been investigated by different researches (LaBoube and Sokol, 2002; Lim and Young, 2007; Lu et al. 2009; Moze and Beg, 2011; Nithyadharan, and Kalyanaraman, 2011). The current design specification for cold-formed steel structures, such as the North American Specification (2007), Australian/New Zealand Standard (2005) and the Eurocode 3 (2006), provide design rules for bolted and screwed connections. These design rules are categorized by different failure modes. However, these design rules of the bolted and screwed connections for cold-formed steel structures in these specifications are slightly different. Various terms may be adopted by different specifications to define a similar failure mode. It should be noted that the design rules for screwed and bolted connection in the current design specifications of cold-formed steel structures are only applicable at ambient temperature condition. The North American Specification (2007), Australian/New Zealand Standard (2005) for cold-formed steel structures improved the bearing factors in the design rules of bearing failure based on hundreds of test specimens conducted by Rogers and Hancock (1998,1999, 2000) at ambient temperature.
The fire resistance of steel structures is an important issue that engineers need to consider. A series of equations was proposed to predict the material properties of cold-formed steel at elevated temperatures based on coupon test results Chen and Young (2007). The experimental investigation on single shear bolted connection specimens of thin sheet steels tested at elevated temperatures using steady state test method is reported by Shu and Young (2011). It was shown that the current design

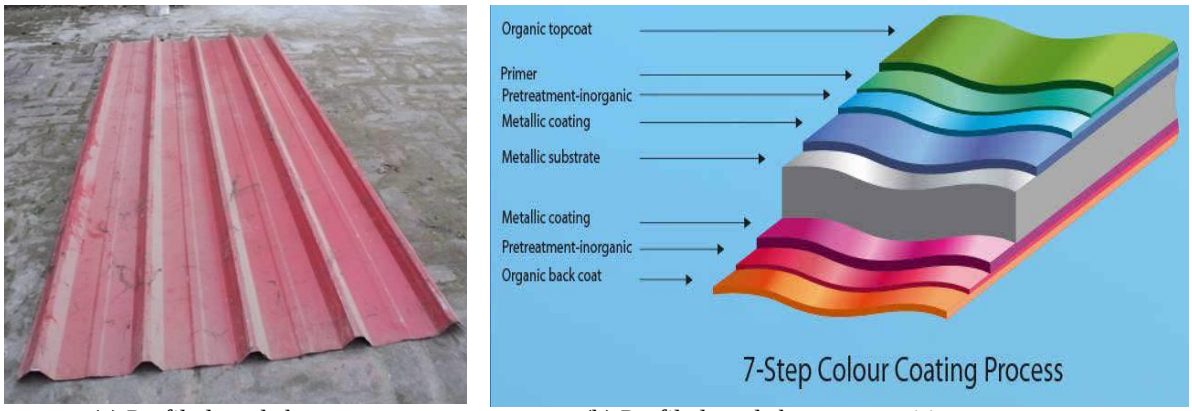
equations of single shear bolted connections in the American (2007), Australian/New Zealand (2005) and European specifications (2006) provide conservative predictions at elevated temperatures by substituting the deteriorated material properties. However, experimental investigation on shear of screw and bolted connections of thin sheet steels at elevated temperatures using the transient state method is limited. There is no research on such connections after elevated temperature. Therefore, an investigation is needed to know the structural behaviour of screw and botted connection of thin profiled steel sheet after elevated temperature. In this study, the structural behaviour of 48 single-double shear bolted and screw connections fabricated were investigated experimentally by varied in bolt size, screw size, bolt arrangement, screw arrangements and 7 different temperatures.

Fig. 1: Field application of profiled steel sheet using bolted and screwed connections

METHODOLOGY

Material Properties

Profiled steel sheet and composition layer of profiled steel sheet is shown in Fig. 2. The tensile coupons were prepared and tested according to the American Society for Testing and Materials Standard, ASTM and the Australian Standard AS 1391 for the tensile testing of metals using 12.5 mm wide coupons. Different heat insulating material which is used in this study is shown in Fig. 2.



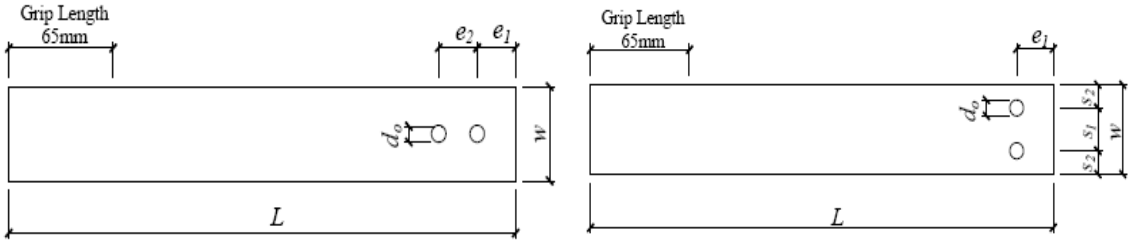
(a) Profiled steel sheet (b) Profiled steel sheet composition

Fig.2: Profile steel sheet and its composition

Test Specimen

A total of 108 connection specimen including 48 connection specimens at elevated temperature were experimentally investigated in this study. In the first step, 60 specimens were tested by connecting with bolts and screws of 3 diffrrent diameter of 5.90 mm, 4.70 mm and 4.30 mm for single shear and double shear conditions to find out suitable connection specimen and optimum bolt and screw dia. Comparing the results for bolted connections the suitable connection type with the optimum bolt diameter was identified for both single shear and double shear conditions. In second step, 48 connection test were conducted using suitable connection type with the optimum bolt diameter which

was heated in different elevated temperatures of 25, 250, 500, 700, 850, 1000, 1250 ºC. At first, the profiled steel sheets were cut with the snipping tools of certain dimensions 300 mm x 200 mm. The test was also conducted in two differen arrangenment of bolt and screw. There are mainly two types connection was adopted for this experiment such as bolt and screw are placed parally or vertically. B2-P (Two bolt parallel conncetion) test specimen and B2-V (Two bolt vertical conncetion) test specimen were adopted for the single shear and double shear bolted connections. The B2-P-test specimen and B2-V-test specimen were connected from end to end with bolts of diameter 5.90 mm, 4.70 mm, 4.30 mm both for single shear and double shear condition as shown in Fig. 3.



(a) B2-P (Two bolt parallel conncetion)

(b) B2-V (Two bolt vertical conncetion)

Fig. 3: Connection details for two bolt parallel and verital conncetions

Test Procedure

A seried of bolted and screwed connection tests were conducted in this study. The bolted and screwed connection tests were conducted by a servo-controlled hydraulic Universal Testing Machine which is mainly used for the coupon tests. Drilling and conneting of tensile test specimen is shown in Fig 4. The connection specimens were set into the grip of the machine as shown in Fig. 5. A pair of grip apparatus was specially fabricated in order to provide pin assembly at both ends of the test specimen. Two special gaskets were inserted in the grips, so that the shear surface of the single and doubly lapped specimen was purely vertical in-line to the loading direction. Clips linked with iron wire were used to prevent the extent of out-of-plane curling at the end of the profile steel sheet. After that, tensile load was applied gradually and the tensile stresses obtained from the machine were recorded at the room temperature. Then, suitable connection type, arrrangement with the optimum bolted & screwed diameter specmens were heated in different elevated temperatures of 25, 250, 500, 700, 850, 1000, 1250 ºC as shown in Fig 6.

RESULTS AND DISCUSSIONS

A total of 108 connected including 48 connections at elevated temperature specimens varied in bolt-screw size, arrangement were tested in 7 different temperatures namely, 25, 250, 500, 700, 850, 1000 and 1250˚C. The failure modes of steel connections were observed carefully and most of the cases the bearing failure occurred as shown in Fig 7-8 and Table1. Diameter of 4.7 and 4.3 mm for screw and bolt connections were found better performance for single shear and double shear respectively.

Fig. 4. Drilling and conneting of tensile test specimen

Fig. 5: Test setup of tensile test specimen

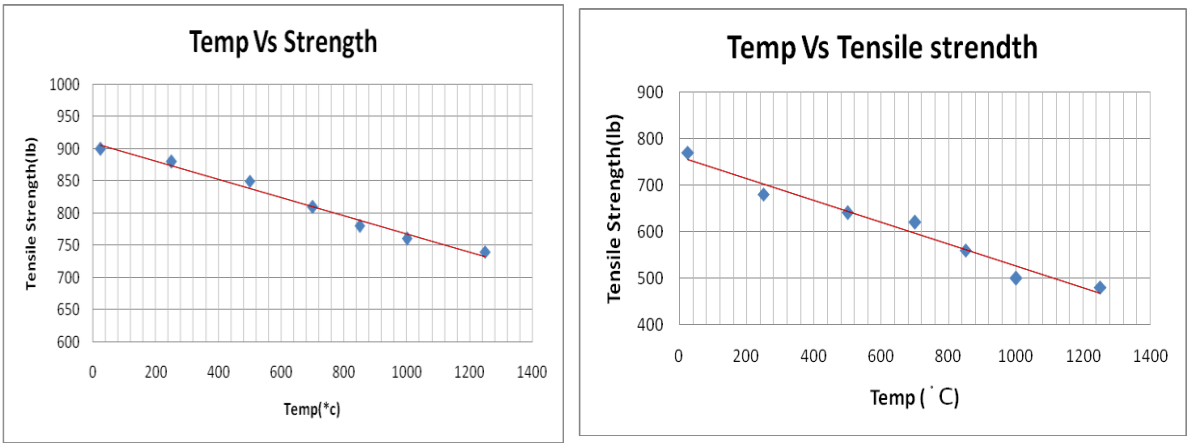
Fig. 6: Specimen at different temperature

Fig.7: Tested failure mode of screw and bolt connection

Fig. 8: Bearing failure after elevated temperature

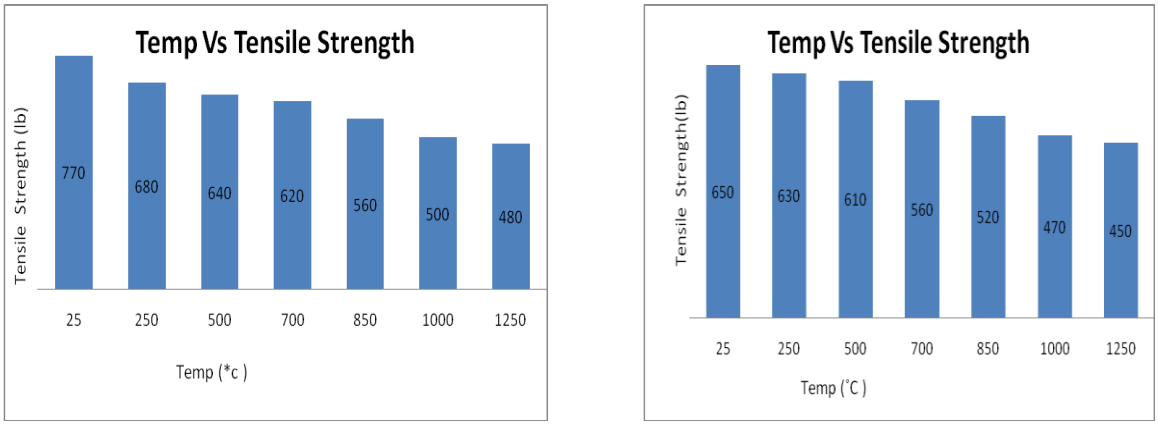
Table 1: Comparison of single and double shear tensile of screw connection after elevated temperatures

Specimen	Length L (mm)	Width W (mm)	Temp (°C)	Tensile Strength (lb)		Failure mode
				Single shear	Double shear	
S2-P- 12	300	50	25	640	560	Bearing Failure
S2-P- 13	300	50	250	600	545	Bearing Failure
S2-P- 14	300	50	500	560	525	Bearing Failure
S2-P- 15	300	50	700	510	485	Bearing Failure
S2-P- 16	300	50	850	480	450	Bearing Failure
S2-P- 17	300	50	1000	430	410	Bearing Failure
S2-P- 18	300	50	1250	410	390	Bearing Failure



(a) Bolted single shear (b) Bolted double shear

Fig. 9: Comparison of tensile strength of single and double shear bolted connection after elevated temperatures



(a) Bolt connection (b) Screw connection

Fig. 10: Comparison of tensile strength of bolted and screwed double shear connection after elevated temperatures

Based on the test results, two bolt or screw parallel connections are proved better performance than vertical arranged at elevated temperature. Single shear screwed and bolted connections are suitable than double shear screwed and bolted connection as shown in Table 1. and Fig. 9. It was found that the tensile strength of profiled steel sheet decreases linearly after the elevated temperatures as shown

in Fig.9. Moreover, it may be concluded that the bolted connections are more satisfactory than the screwed connections after the elevated temperatures as shown in Fig 10.

CONCLUSION

A series of test program on the structural behaviour of single-double shear, bolted and screwed connections of thin sheet steels at elevated temperatures has been presented. A total of 108 including 48 connections at elevated temperature specimens varied in bolt-screw size, arrangement were tested in 7 different temperatures namely, 25, 250, 500, 700, 850, 1000 and 1250˚C. According to the test results, bearing failure mode were found most of the specimen at elevated temperature. The optimum diameter of 4.7 and 4.3 mm for screw and bolt connections were found for single shear and double shear respectively. Based on test results, two bolt or screw parallel connections are proved better performance than vertical arrange at elevated temperature. Single shear screwed and bolted connections are found suitable than double shear screwed and bolted connection. It was found that the tensile strength of profiled steel sheet decreases linearly after the elevated temperatures. Furthermore, it may be concluded that the bolted connections are more satisfactory than the screwed connections at the elevated temperatures. The comparison of the test strengths of single-double shear bolted-screwed connections with the tensile strengths of the material properties of the corresponding sheet steels obtained from the coupon tests has a similar tendency of deterioration at elevated temperatures.

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