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Wei Chen

Yihong Ye

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Shear behavior of screw connection between cold formed steel and gypsum sheathing at elevated temperatures

Wei Chen[1], Jihong Ye[2]

Abstract

The screw connections between cold-formed steel (CFS) and gypsum sheathing play an important role in the axial and lateral performance of CFS wall panels. Previous researches were mainly focus on the shear behavior of such screw connections at room temperature. This paper carried out a preliminary experimental investigation on the mechanical performance of screw connections with single layer gypsum sheathing at elevated temperatures. Limited to the cavity dimension of the furnace, the single-lap test of CFS coupon -fastener-sheathing connection was adopted and compared with the previous test results of sheathing-to-profile screw connections at room temperature. The failure of screw connections with single layer gypsum sheathing was identified as the breaking of the sheathing edge at elevated temperatures and a sharp decrease of the shear strength was observed beyond 150 °C. In addition, the load-displacement curves of screw connections were well predicted by an exponential model with the post-peak branch at elevated temperatures.

[1] PhD, Key Laboratory of Building Fire Protection Engineering and Technology of MPS, Tianjin; Key Laboratory of Concrete and Prestressed Concrete Structures of the Ministry of Education, Southeast University, Nanjing, China

[2] Professor, Key Lab. of Concrete and Prestressed Concrete Structures of the Ministry of Education, Southeast University, Nanjing, China

Key words: shear behavior; screw connection with gypsum sheathing; elevated temperatures; cold-formed steel

Introduction

With the growing construction of mid-rise cold-formed steel (CFS) structures, the fire performance of such structures receive great concerns. As the major connection method, the CFS screw connections play an important role in both axial and lateral performance of CFS wall panels. Some experimental investigations (Fiorino et al. 2007; Fülöp and Dubina 2006; Nithyadharan and Kalyanaraman 2011; Peterman et al. 2014; Serrette et al. 1997; Ye et al. 2016) have already been conducted on the shear response of screw connections with gypsum sheathing or other board materials at ambient temperature. Gypsum sheathing does not have a preferential material response in a specific direction (Peterman et al. 2014) and the failure of screw connections with single-layer gypsum sheathing was mainly identified as breaking or bearing of the loaded sheathing edge (Fiorino et al. 2007; Peterman et al. 2014; Ye et al. 2016). Furthermore, the effect of the loading rate, steel thickness, loaded edge distance and loading protocol were also discussed with explicit conclusions. Some mathematical models, such as the Foschi model (Foschi 1974), Pivot model (Dowell et al. 1998) and Pinching 4 model (Peterman et al. 2014), were used to describe the monotonic or cyclic load-displacement characteristic of connections at ambient temperature. In addition, a few experiments were conducted on the mechanical behavior of CFS sheeting-fastener-sheeting connections at elevated temperatures (Cai and Young 2014; Lu et al. 2011; Yan and Young 2012). However, investigation on the screw connections with board sheathing materials at elevated temperatures is still limited, leading to the ignorance of mechanical contribution of gypsum sheathing in the previous investigation of CFS walls under fire conditions (Chen et al. 2014; Gunalan 2013).

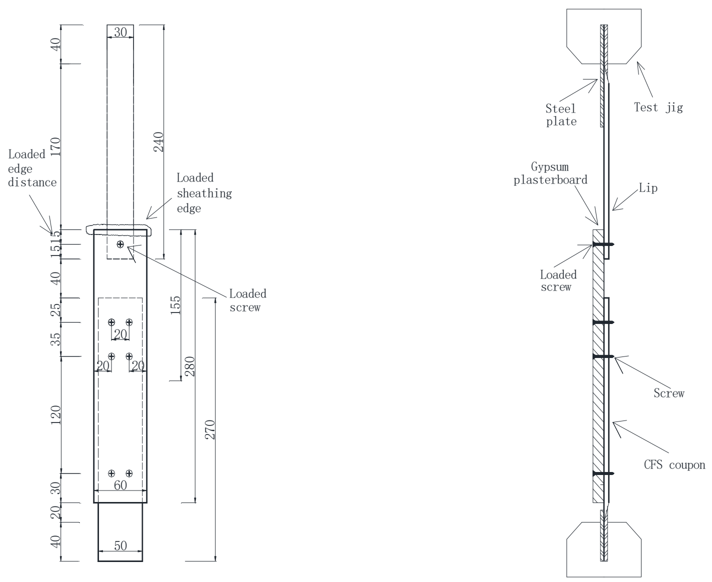
This paper carried out a preliminary experimental investigation on the mechanical performance of screw connections with single layer gypsum sheathing at elevated temperatures. The test scheme of single-lap coupon-fastener-sheathing connection was compared with the multi-screw sheathing-to-profile connection at ambient temperature. The failure mechanics of screw connections was described and the load-displacement response of screw connections was predicted by an exponential model at elevated temperatures.

Test procedure

Fig. 1 presents the test system, including an electronic universal material testing machine with a loading capacity of 50kN and a cylindrical electric furnace with the cavity diameter of 85mm and cavity height of 280mm. Limited to the cavity dimension of the furnace, the single-lap test of CFS coupon-fastener-sheathing connection was adopted and consisted of single layer 12.5 mm thick gypsum plasterboard and 1.0 mm thick G550 CFS coupon by 4.2 mm diameter screws, as shown in Fig. 2. The loaded edge distance of screw connections was 15mm. In addition, the lipped was designed for the CFS coupon to avoid the out-of-plane curling of CFS sheets.

Fig. 1 Test system in this paper

At the beginning of experiments, the specimen was mounted into the loading machine by gripping the upper end of specimen and relaxing the bottom end. Then, the furnace was heated up to the pre-set temperature and held for 120 minutes at this constant temperature. Subsequently, the bottom end of specimen was manual gripped and a monotonic tension load was applied gradually to the specimen at a constant displacement rate of 0.025mm/s until failure while maintaining the pre-set temperature. Eight temperature levels were considered in the present experiments, including the ambient temperature (approximately 20°C), 100°C, 150°C, 200°C, 250°C, 300°C, 350°C and 500°C. Each temperature series were repeated three times.



(a) Front view (b) Side view

Fig. 2 Details of screw connection with single layer sheathing and loaded edge distance of 15mm

Test results

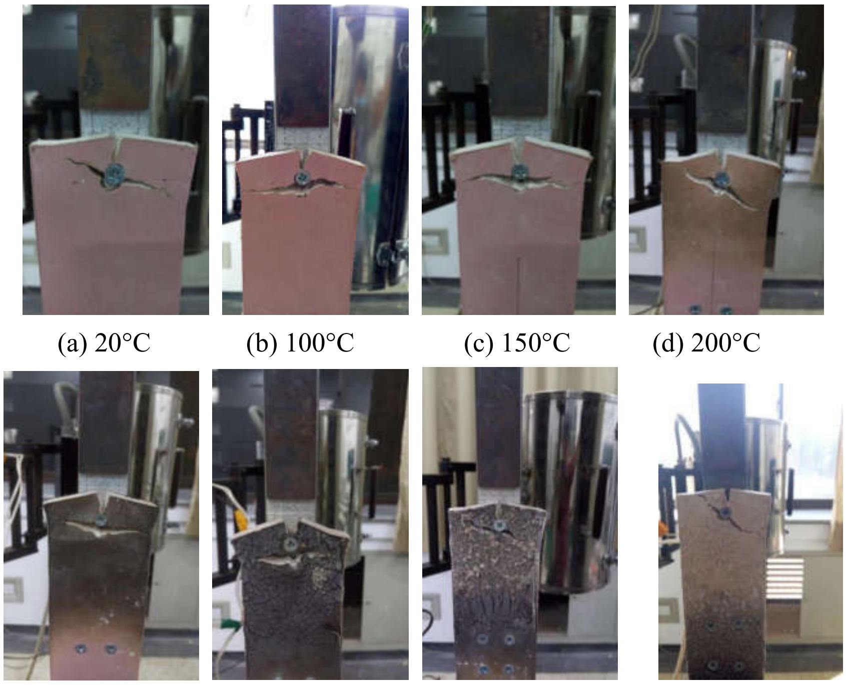
For illustration, all of the specimens were labeled according to the following rule: the first group of characters represent the sheathing material (GPB: gypsum plasterboard); the second group of characters represent the temperature for the experiment (20 (ambient temperature) or 100, 150…500°C), the last group indicates the number of repeated experiments with the same temperature series. Table 1 summarizes the test results for each specimens. F_{mT} represents the shear strength of the specimen at T°C; Δ_{mT} is the recorded displacement corresponding to F_{mT} at T°C; Δ_{uT} is the recorded displacement corresponding to $0.8F_{mT}$ on the post-peak branch of response at T°C; E_T represents the absorbed energy of the screw connection at T°C, which is the area under the load-displacement curve up to Δ_{uT}. The other parameters in table 1 are described in Fig. 6. In table 1, the scatter of the test results is significant, except for F_{mT}. Both F_{mT} and E_T of the screw connection decreased with increasing temperatures. However, Δ_{mT} of the specimens at 100°C became much lower than that of the series at ambient temperature and 150°C. No reasonable explanation is currently offered for such phenomenon.

Table 1 Test results of single-lap connection at elevated temperatures

Specimen	F_{mT} (N)	Δ_{mT} (mm)	Δ_{uT} (mm)	E_T $(N \cdot mm)$	$K_{1T}(N/mm)$	$K_{2T}(N/mm)$	F_{0T} (N)	$K_{3T}(N/mm)$
GPB20-1	544	1.16	1.53	0.588	762	632	-1281	-294
GPB20-2	582	0.87	1.34	0.587	1185	959	-1308	-248
GPB20-3	569	0.85	1.35	0.540	879	457	-653	-228
GPB100-1	479	0.73	0.95	0.284	695	287	-411	-432
GPB100-2	489	0.54	0.71	0.223	1005	388	-320	-582
GPB100-3	451	0.58	0.79	0.245	1277	2355	-2929	-436
GPB150-1	314	0.68	1.04	0.226	554	263	-310	-173
GPB150-2	344	0.82	1.14	0.262	508	240	-341	-218
GPB150-3	346	0.67	0.88	0.189	490	166	-168	-343
GPB200-1	207	0.62	0.78	0.152	519	93	167	-259
GPB200-2	205	0.67	1.46	0.240	737	-566	830	-52
GPB200-3	193	0.29	0.78	0.108	324	625	12	-80
GPB250-1	151	0.43	0.56	0.055	420	168	-98	-227

GPB250-2	157	0.52	1.12	0.134	442	-267	619	-53
GPB250-3	176	0.77	1.19	0.152	487	959	-1081	-85
GPB300-1	173	0.74	1.20	0.151	372	543	-876	-76
GPB300-2	148	0.51	1.04	0.120	482	277	-199	-56
GPB300-3	162	0.53	0.86	0.100	412	192	-149	-98
GPB350-1	146	0.54	0.96	0.104	345	153	-123	-70
GPB350-2	128	0.48	0.87	0.085	434	229	-150	-66
GPB350-3	147	0.60	1.03	0.114	337	146	-118	-68
GPB500-1	114	0.47	0.57	0.040	257	97	-70	-230
GPB500-2	100	0.33	0.42	0.028	446	373	-242	-230
GPB500-3	100	0.40	0.53	0.034	273	112	-74	-153

After the experiments, the off-test inspection indicated that (1) the color of the paper facing on the gypsum plasterboard remained stable below 150°C (Fig. 3c) and gradually changed to light gray (200°C, Fig. 3d), black (250°C, Fig. 3e), and white (500°C, Fig. 3h) with increasing temperature. In addition, the paper facing on the gypsum plasterboard maintained integrity below 250°C and significantly cracked at 300°C (Fig. 3f). Beyond 350°C (Fig. 3g), the paper facing on the gypsum plasterboard began to fall off. Therefore, the sharp degeneration of the shear strength of the connection series at 150°C (Table 1) was likely due to the dehydration of the gypsum, and the effect of the paper facing on the shear behavior of the connection become insignificant beyond 300°C. In addition, all the specimens demonstrated the breaking of the loaded sheathing edge at ambient and elevated temperatures. No titling and pull through of screws were found in the experiments.



(a) 20°C (b) 100°C (c) 150°C (d) 200°C

(e) 250°C (f) 300°C (g) 350°C (h) 500°C

Fig. 3 Failure mode of screw connections at elevated temperatures

Comparison with the previous experiment

Ye et al. (2016) carried out the shear experiments of multi-screw sheathing-to-profile screw connections at ambient temperature. The adopted loading device was a hydraulic universal testing machine with a loading capacity of 100kN. Fig. 4 showed the typical test curves of screw connections with the same component material obtained from the present experiments and previous experiment (Ye et al. 2016). The results showed that (1) the shear strength from multi-screw sheathing-to-profile screw connection was 577N and very close to that from single-lap coupon-fastener-sheathing connection (544~582N in table 1); (2) a significant jitter existed in the load-displacement curve of multi-screw sheathing-to-profile screw connection, due to the hydraulic loading system;

while, the load-displacement curve became stable using electronic loading system; (3) the load-displacement curve of multi-screw sheathing-to-profile screw connection was much plumper than that from single-lap coupon-fastener-sheathing connection, leading to a better capacity of energy absorb and a later appearance of Δ_{mT} . This difference was probably due to the additional deflection of the sheathing-to-profile screw connection during the loading, as shown in Fig.5. Besides, the specimens from different test scheme demonstrated the same failure mode, which was described as the breaking of the loaded sheathing edge. Moreover, the initial stiffness of load-displacement curve was not analyzed due to the significant scatter of test results (K_{1T} in table 1). Based on the above comparison, it could be preliminary indicated that replacing the multi-screw sheathing-to-profile screw connection with the single-lap coupon-fastener-sheathing connection might result in conservative test results and would significantly reduce the processing cycle of specimens, because there is only one loaded screw on the loaded edge of sheathing material.

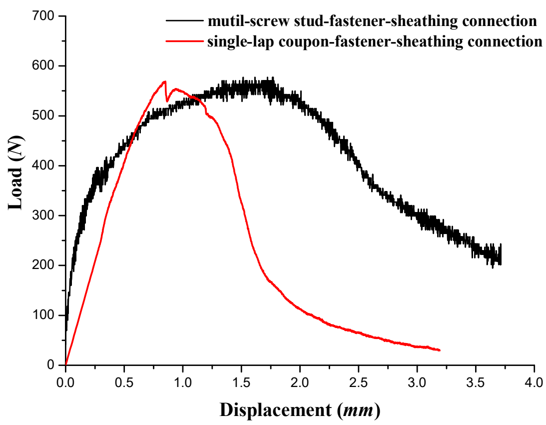


Fig. 4 Load-displacement curve of screw connections at ambient temperature

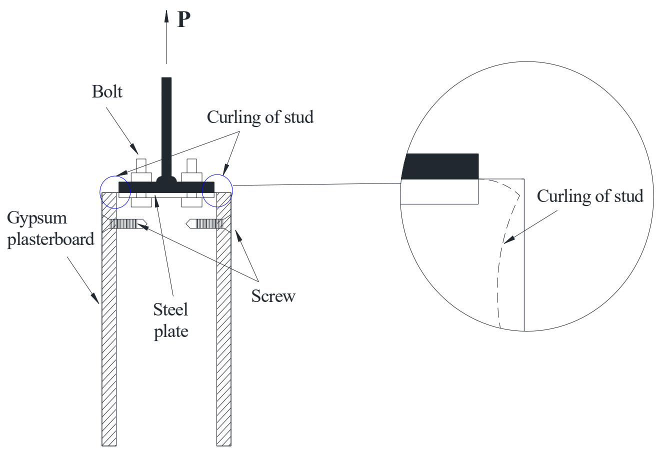


Fig. 5 Additional deflection of the sheathing-to-profile screw connection

Load-displacement model of the screw connection

The load-displacement curves of the screw connection at ambient and elevated temperatures are important input parameters for the elaborate simulation of the mechanical performance of CFS walls at ambient temperature or in fire conditions. Eq. (1) is an exponential model with the post-peak branch proposed by Foschi et al. (1974) to describe the load-displacement curve of nail connection at ambient temperatures, as shown in Fig. 6. Based on the present exponential model, the load-displacement response of screw connections at elevated temperatures are predicted, as shown in table 1. Fig. 7 compared the load-displacement curves predicted by Eq. (1) to the experimental results. In Fig. 7, the parameters of Eq. (1) (F_{mT} and Δ_{mT}) were obtained from the table 1. It was shown that the load-displacement curves of screw connections obtained from Eq. (1) were in good agreement with the experimental results.

$$F_T = \begin{cases} (1-\mathrm{e}^{\frac{-k_{1T}}{F_{0T}}})(\mathrm{F}_{0T}+k_{2T}\cdot\Delta_T)\,, & \Delta_T \le \Delta_{mT} \\ F_{mT}+k_{3T}(\Delta_T-\Delta_{mT})\,, & \Delta_T \le \Delta_{uT} \end{cases} \quad (1)$$

where Δ_T is the connection displacement at T°C; F_T is the connection shear load at T°C; F_{0T}, $k_{1T,}$ k_{2T} and k_{3T} are described in Fig. 6.

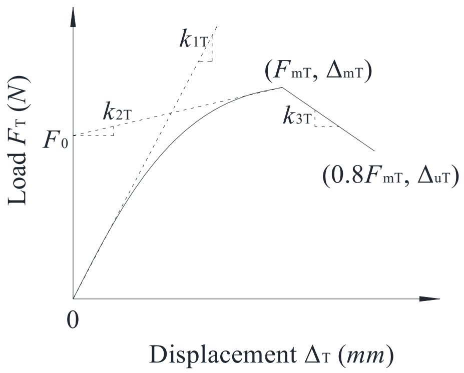


Fig. 6 An exponential model with the post-peak branch

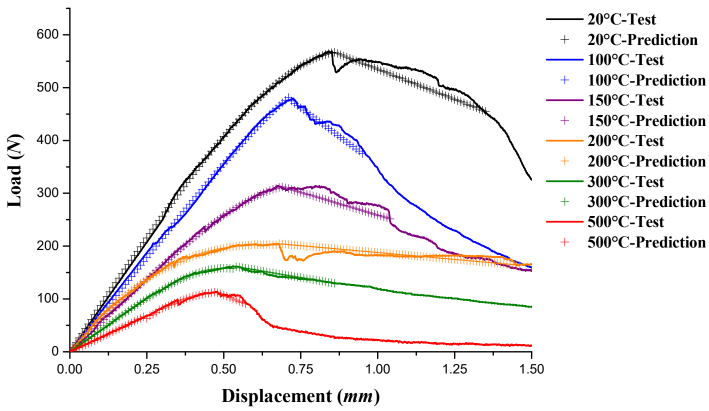


Fig. 7 Comparison of the predicted load-displacement curves to the experimental results

Conclusions

This paper presented a preliminary experimental investigation on the mechanical performance of screw connections with single layer gypsum sheathing at elevated temperatures. The test scheme of single-lap coupon-fastener-sheathing connection was compared with the multi-screw sheathing-to-profile connection at ambient temperature and might provide conservative results of the load-displacement response of screw connections. In addition, The failure of screw connections with single layer gypsum sheathing was identified as the breaking of the sheathing edge at elevated temperatures and a sharp decrease of the shearing strength was observed beyond 150 °C due to the dehydration of gypsum plasterboard. Moreover, the load-displacement curves of screw connections was described by an exponential model with sufficient accuracy. Based on the present investigation, a series of further experiments on screw connections are scheduled and will be presented later.

Acknowledgments

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References

Cai Y. C. and Young B. (2014). "Behavior of cold-formed stainless steel single shear bolted connections at elevated temperatures." *Thin-Walled Struct.*, 75, 63-75

Chen W., Ye J. H., Bai Y. and Zhao X. L. (2014). "Thermal and mechanical modeling of load-bearing cold-formed steel wall systems in fire." *J. Struct. Eng.*, 140 (8), 1- 13

Dowell R. K, Seibel F. and Wilson E. L. (1998). "Pivot hysteresis model for reinforced concrete members." *ACI Struct. J.*, 95(5), 607-617

Fiorino L., Della Corte G. and Landolfo R. (2007). "Experimental tests on typical screw connections for cold-formed steel housing." *Eng. Struct.*, 29, 1761-1773

Foschi R. O. (1974). "Load-slip characteristics of nails." *Wood Science*, 7(1), 69-76

Fülöp L. A. and Dubina D. (2006). "Design criteria for seam and sheeting to framing connections of cold-formed steel shear panels." *J. Struct. Eng.*, ASCE, 132(4), 582-590

Gunalan S. and Mahendran M. (2013). "Finite element modelling of load bearing cold-formed steel wall systems under fire conditions." *Eng. Struct.*, 56, 1007-1027

Lu W,. Mäkeläinen P., Outinen J. and Ma Z. C. (2011). "Design of screwed steel sheeting connection at ambient and elevated temperatures." *Thin-Walled Struct.*, 49, 1526-1533

Nithyadharan M. and Kalyanaraman V. (2011). "Experimental study of screw connections in CFS-calcium silicate board wall panels." *Thin-Walled Struct.*, 49, 724-731

Peterman K. D., Nakata N. and Schafer B. W. (2014). "Hysteretic characterization of cold-formed steel stud-to-sheathing connections." *J. Constr. Steel Res.*, 101, 254-264

Serrette R.L., Encalada J., Juadines M. and Nguyen H. (1997). "Static racking behavior of plywood, OSB, gypsum, and fiberboard walls with metal framing." *J. Struct. Eng.*, ASCE, 123(8), 1079-1086

Yan S. and Young B. (2012). "Screwed connections of thin sheet steels at elevated temperatures - Part Ⅰ: Steady state tests." *Eng. Struct.*, 35, 234-243

Ye J. H., Wang X. X and Zhao M. Y. (2016). "Experimental study on shear behavior of screw connections in CFS sheathing." *J. Constr. Steel Res.*, 121, 1-12