CONNECTIONS OF TRAPEZOIDAL SHEETS UNDER FIRE

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ABSTRACT

The paper describes experiments with screwed connections of thin walled corrugated sheets using self-drilling screws at the ambient and elevated temperatures. The connection has significant influence on the ultimate capacity of the structure exposed to fire. In the first phase of the fire the sheet behaves as a simple supported beam, in the second phase the load bearing is transferred by a tension membrane. The tensile reaction from the sheet to supports is transferred by the bolted connections. Resistance of the connection decreases as the temperature increases except for temperature up to approximately 250°C when the connection reaches its highest resistance.

1 INTRODUCTION

The structural response at fire is influenced by the material properties, the thermal expansion and the reduction of mechanical properties of steel at high temperature, see [1]. This is significant especially for thin-walled elements, whose temperature almost follows the fire curve. The corrugated sheet is able to transfer the bending moments at the early stages of the fire. The thermal expansion of steel leads to extension of sheet and results in increased deflection. At this stage the bolted connection is loaded by forces induced by thermal expansion. At higher temperatures the bending moment resistance is reduced and major part of the load is transferred by tension membrane. At this moment the resistance and stiffness of the bolted connection has significant influence on the sheet behaviour. The connections transfer the membrane force to the supports. The performance of the connection is important also at the cooling phase of the fire.

The resistance of the connection is influenced by mechanical properties of the corrugated sheet. Effective yield stress and modulus of elasticity of cold formed steel is reduced at high temperatures, see [2], which leads to reduction of the load bearing capacity of the structure. The ultimate strength is slightly increased for high temperatures, see [3]. The maximum strength is reached at 250°C and then the original value is obtained at about 350°C and is further reduced at higher temperatures. Buckling of the thin walled elements is influenced by reduced value of modulus of elasticity, see [2].

2 EXPERIMENTS

Experiments with bolted connection at high temperatures were carried at laboratory of Faculty of Civil Engineering, Czech Technical University in Prague. The experiments are focussed on stiffness, resistance, deformation capacity and collapse mode of the connections at fire. New experiments using sheets thickness 0.88 mm, 1.00 mm and 1.25 mm are in preparation.

2.1 Recent experiments

Two types of the connection using bolts E-VS BOHR 5-5,5×38 were tested in 2005 [5]. Bolts with sealed washer ø19 mm were used for the first set. For the next two sets, the sealed washer was replaced by steel washer ø29 mm, see Fig. 1. The test specimen’s thickness 0.75 mm was connected to 10 mm steel plate representing the support of the sheet. The tests were carried out at constant temperatures 20°C, 200°C, 300°C, 400°C, 500°C, 600°C and 700°C. The experiments were focussed on stiffness, resistance, deformation capacity and collapse mode of the connections.
The resistance of the connection with sealed washer was limited by bearing resistance of the thin sheet. The flexible washer does not have any influence on the behaviour because the sealant burns at higher temperatures. The stiffness of the connection with steel washers is much higher and the resistance is almost doubled compared to the previous set. The thin sheet was deformed and accumulated in front of the washer which was accompanied by creation of two shear zones on both sides of the washer. This failure mode is characterised by deformation capacity larger than 30 mm. However, at temperatures higher than 500°C shear failure of the bolt was observed, see Fig. 2b. This failure mode has limited deformation capacity and should be avoided.

2.2 Experiments 2007

New experiments were performed in 2006-2007, see [4]. The specimens were tested at constant temperatures 20°C, 200°C, 300°C, 400°C, 500°C, 600°C a 700°C. Two specimens were tested at each temperature. The test set up is shown on Fig. 3. The tested specimens were taken from trapezoidal sheets with nominal thickness 0.75 mm. The measured thickness of the specimens in the first set (tested in 2006) was 0.75 mm, size 75×500 mm, yield stress 338 MPa and ultimate strength 428 MPa. The properties of the specimens in the second set (tested in 2007) are: thickness 0.80 mm, size 50×350 mm, yield stress 327 MPa and ultimate strength 426 MPa. The lower part of the specimen was attached to the steel plate of thickness 10 mm representing beam flange. One self-drilling screw SD8-H15-5.5×25 (ø5.5 mm, length 25 mm,
Bolt head diameter 14.5 mm) was used. The other end was attached by standard bolt M12 to 10 mm steel plate to allow loading of the specimen.

The tested connection in the furnace was fixed to testing machine. Screw SD8 - H15 - 5,5 × 25 was used. The other end was attached by standard bolt M12 to 10 mm steel plate to allow loading of the specimen. Steel plate t = 10 mm fixed to testing machine. Bolted connection, standard bolt M12. Test specimen t = 0,75 mm. The tested connection in the furnace.

The specimens tested in 2006 were heated in electric furnace with internal diameter 150 mm and height 300 mm, see Fig. 4a. Temperature of the connection was measured by thermocouple attached to steel sheet close to the bolt.

New furnace was used for experiments performed in 2007. Smaller size of the specimens should be used as internal dimensions of the furnace are 50×130×125mm, see Fig. 4b. The window in the furnace allows to observe the connection behaviour at high temperatures. The deformations of the connection were recorded by a camera located in front of the window. The photographs were taken in 5 seconds interval. The edge of the specimen is marked at spacing 5 mm for displacement measurement, see Fig. 5.

The temperature in the furnace and temperature of the connection were measured by thermocouples. The thermocouple measuring of the connection temperature was located in a small hole in the bolt head.
The experiments were performed at constant temperature; the loading was controlled by deformation. The collapse at various temperatures is shown on Fig. 6.

The force-deformation relationship was recorded during the test. The deformation was measured at grips of the testing machine and includes the initial slip and deformation of the connection using M12 bolt. This deformation can be neglected as the connection is outside the furnace. The initial slip was eliminated from the diagrams, see Fig. 7.
The resistance of the connection was limited by the bearing resistance of the steel sheet. Shear failure of the bolt was observed at temperature 700°C, one specimen thickness 0.80 mm. The resistance is reduced by the temperature: at the temperature 500°C the resistance drops to approximately 50% of the resistance at 20°C, and to 20% at 700°C. The temperature does not have significant influence on the initial stiffness of the connection at temperature lower than 500°C. Deformation capacity of the connection is larger than 25 mm for the tests where the collapse is limited by bearing resistance of the sheet. The tests were stopped at deformation 35 mm, at the tests in 2006, or 30 mm, at the tests in 2007, to avoid damage of the furnace. The deformation capacity is significantly lower when shear failure of the bolt occurs, see Fig. 7b, temperature 700°C.

### 3 CONCLUSIONS

Resistance of the connection in relation to temperature is shown on Fig. 8. Resistance is reduced at higher temperatures; the reduction is small at temperatures up to 400°C but significant at temperatures higher than 500°C.

The diameter of the washer or of the bolt head has significant influence on the resistance. The resistance of connection using screws E-VS BOHR 5-5.5×38 with sealed washer is approximately 40% lower than resistance of the connection with SD8-H15-5.5×25. When screws E-VS BOHR 5-5.5×38 with steel washers are used, the resistance is similar to connection with SD8-H15-5.5×25. Shear failure of the screw may lead to low deformation capacity at temperature higher than 500°C. These experiments will be used for development of design model of the connections at high temperatures. Preparation of the model is in progress.
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REFERENCES


