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Behavior of welded connections after exposure to elevated temperature

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ABSTRACT

This paper reports test results showing how the heating-cooling process like the one occurring during fire action can affect the tensile strength and the deformation after rupture of the welded connections normally used in steel structures. Tests were carried out to assess the values of these properties for butt welded, transverse and longitudinal fillet welded connections after heating. Different configurations of weld specimens, made of Q345 steel, were first heated to a specified target temperature in 200 to 800 °C range, then cooled to ambient temperature, and finally loaded to failure. Cooling in the air and cooling by water jet were the cooling processes used. All connections were designed to fail in the base metal at room temperature. Test results show that butt welded connections attain failure in the weld region when heated to above 400 °C (and cooled under natural cooling) or 500 °C (under water cooling regime), which showing butt welds experience greater tensile strength degradation than the base metal after exposure to larger temperatures. Moreover, natural cooling generally produces higher strength and deformation degradation in butt welds than water cooling. In contrast to butt welded connection specimens, the transverse and longitudinal fillet welded connection specimens experience failure in the base metal throughout 20–800 °C exposure range. Further experimental research on fillet welds is needed to evaluate the residual behavior of fillet welded connections after exposure to elevated temperatures.

1. Introduction

Steel structures experience loss of strength and stiffness under high temperature exposure [1]. Inspection reports from fire incidents indicate that in most cases fire exposed steel structures retain much of their load bearing capacity up on cooling. Thus, in many cases fire exposed steel structures can be reused after structural safety appraisal and necessary retrofit. So it is imperative to ascertain the post-fire residual capacity of steel structures.

Connections play a critical role in determining fire resistance of steel structures, and welded and bolted connections are widely used in steel framed buildings. Although numerous studies on the capacity degradation in welded and bolted connections during heating phase are reported in the literature [2–9], only few studies are undertaken on the behavior of connections following heating and cooling phase [10–15], as encountered in realistic fire incidents in buildings.

Provisions in published papers and design codes infer that failure in welded connections occur in the base metal instead of the weld region. This is based on observations and recordings during heating conditions, and yet this may not be the case in welded connections after cooling down to ambient conditions. Further, chemical composition of base metal and filler metal are different, and the effects of heating and cooling are similar to tempering and annealing, thus different transformations in the metal structures may occur in the base metal and the weld region. Therefore data on the residual mechanical properties specific to different weld types is required for assessment of residual load-bearing capacity of fire-exposed steel structures.

A review of current literature indicate that there is limited data on the residual strength of fire-exposed S355JR butt welds [13], A588 transverse fillet welds [14] and Q235 (equivalent to ASTM A283 GrC [16]) transverse fillet welds [15]. However there is a lack of thorough research and understanding on the post-fire behavior of welded connections made of Q345 steel (equivalent to ASTM A572 Gr50 steel [17]), which is most widely used in Far East. In the event of fire design, connections may be subjected to rapid cooling, resulting from quenching of fire through water, or slower natural cooling through air. The mechanical properties of the welds may be differently affected based on cooling regime. Also the level of maximum temperature experienced in the welds during a fire can be different in different fire scenarios. Preheating can be defined as the application of heat to the base metal or substrate before welding. Gas torches, electric heaters, or infra-red radiant pane heaters can all be used to apply preheat, which decreases the weld cooling speed and thereby prevents cold cracking in welds.

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Table 1
Chemical composition of metal materials used in welded connections.

Metal material	Chemical composition (%)													
	C	Mn	Si	S	P	V	Nb	Ti	Al	N	Cu	Cr	Ni	Mo
Base metal (Q345B)	0.16	1.50	0.35	0.028	0.028	0.10	0.03	0.12	–	–	–	–	–	–
Filler metal (ER50-6)	0.08	1.52	0.92	0.015	0.020	–	–	–	0.60	–	0.20	–	–	–

Preheating rate, provided by different preheating methods and devices, may be another factor which can affect the residual strength of welds. A lower preheating rate may cause less change in the residual strength of welds after heating. In this study, the cooling regime and maximum exposure temperature are chosen as the test variables.

This paper presents results from tests on 117 welded connection specimens made of Q345 steel, and the effect of maximum exposure temperature and cooling regime on residual tensile strength and deformation of butt welded, as well as transverse and longitudinal fillet welded connections, is discussed.

2. Experimental program

As part of experiments, a total of 117 test specimens, including 39 butt welded connections, 39 transverse fillet and 39 longitudinal fillet welded connections, were tested. In each test, failure mode as well as location of fracture, and load-deformation response of welded connection is recorded.

2.1. Fabrication of test specimens

The test specimens were designed in accordance with GB50017 [18], so that failure at room temperature will occur in the base metal. If failure would occur in the weld region after heating-cooling cycle, it infers that the welds would experience larger strength degradation than the base metal during heating-cooling process. All test specimens were made from Q345B steel (equivalent to ASTM A572 Gr50 steel [17]), with a measured ultimate strength of 531 MPa and measured yield strength of 353 MPa. The welding process adopted was CO_2 gas shielding arc welding and the electrode type is ER50-6 (equivalent to AWS ER70S-2 [19]), with a nominal ultimate strength of 550 MPa and nominal yield strength of 430 MPa. The chemical composition of the steel and the electrode is presented in Table 1. Dimension of typical butt welded specimen is shown in Fig. 1a. To ensure the entire length of the weld is of good quality and that none of it is affected by the stop or start of the welding process, specimens are sampled from a large welded plate as shown in Fig. 1b. Similarly, diagram of a fillet welded specimen is shown in Fig. 2.

In addition to type of welding, other variables considered in the tests included level of heating temperature level, cooling regime adopted to cool down the heated specimen to ambient temperature. Six temperature levels T_s were considered for heating, namely 200 °C, 400 °C, 500 °C, 600 °C, 700 °C and 800 °C. Tests at ambient temperature were

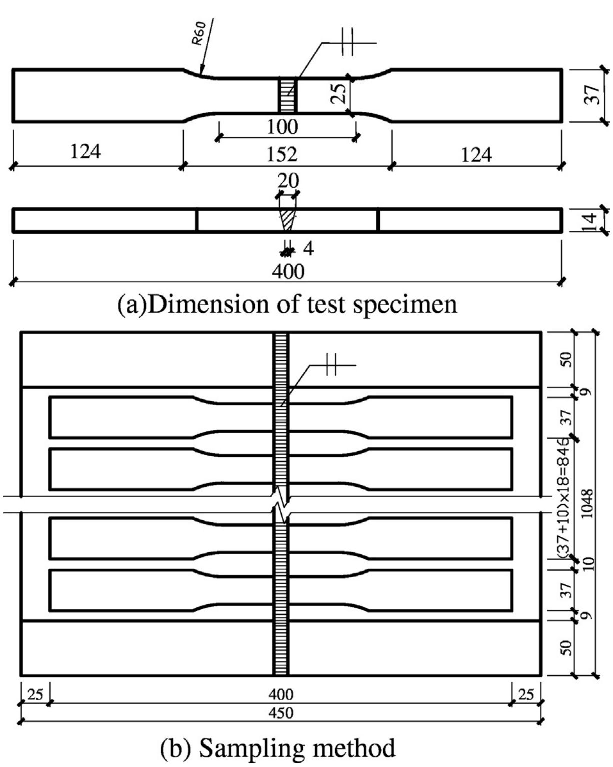

Fig. 1. Preparation of butt weld connection specimens for tests.

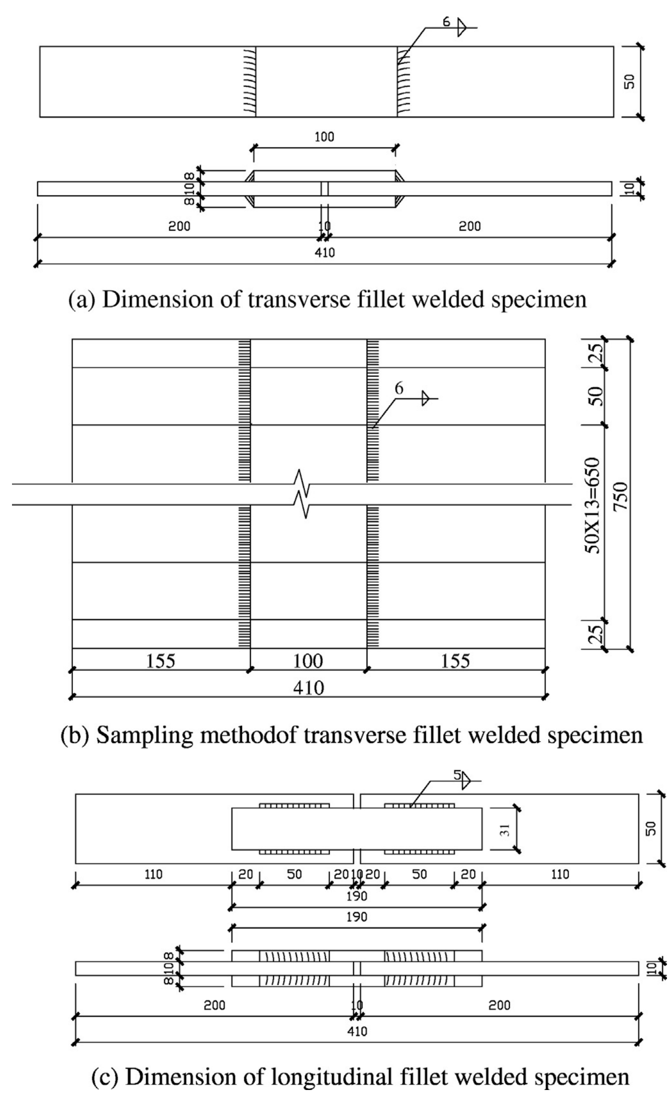

Fig. 2. Fillet weld specimen diagram.