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Post weld heat treatment for high strength steel welded connections

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ABSTRACT

In this study, experiments were conducted to investigate the effect of post-weld heat treatment (PWHT) on the reheated, quenched and tempered (RQT) grade S690 high strength steel welded connections. Firstly, the effect of PWHT on the mechanical properties after welding is investigated. It is found that the loss of both strength and ductility after welding could be serious but PWHT could be able to improve the ductility of the affected specimens at the expense of strength. Secondly, four Y-shape plate-to-plate (Y-PtP) and nine T-stub RQT-S690 joints are fabricated to study the effect of PWHT on the residual stress level near the weld toe and the tensile behavior of the joints, respectively. The hole drilling tests employed to study the residual stress reveal that PWHT is able to decrease the residual stress level near the weld toe significantly. The tensile test results show that proper PWHT could improve both the ductility and the maximum resistance while the reduction of plastic resistance can be kept in a negligible level. However, it is found that if the specimens are overheated, although the ductility could still be increased, the reduction of load carrying capacity was severe.

1. Introduction

Heat input is essential in most discussions related to the process of welding in structural steel connections. Heat input during welding produces a variety of structural, thermal and mechanical effects into the heat affected zone (HAZ) such as expansion and contraction, metallurgical changes and compositional changes [1]. Steels are more significantly altered by the heat of welding than other metals. In particular, high strength steels including heat treatment or work hardened steels are the most sensitive types [2]. Researchers have shown that the welded quenched and tempered steel structures are accompanied by higher amount of residual stress than normal strength steel structures [3,4], and the deterioration of mechanical properties in the HAZ including strength, hardness, ductility and toughness is inevitable [5]. As a result, there are concerns about the performance of welded high strength steel connections under both static and dynamic applications. Specifically, fatigue performance is frequently a concern since failure very often initiates at the weld toe area which could be affected by welding heat input [6].

Post-weld heat treatment (PWHT) is normally applied to mild steel weldment to remove residual stress, restore deformations during welding or improve the load-carrying capability in the brittle fracture temperature range of service. In fact, the beneficial effects of PWHT are not primarily due to reduction of residual stresses, but rather due to improvements of metallurgical structure by tempering and removal of aging effects [7]. This process is widely accepted as beneficial for mild steel weldment since the microstructure of mild steel, i.e. the mixture of pearlite and proeutectoid ferrite formed at temperature above normal PWHT range, would be hardly altered unless the time of heating is prolonged or higher than usual temperature are employed during the treatment [2]. However, PWHT may introduce unpredictable changes into the microstructure of hardened or high strength steel weldment, which is extremely complicated and normally very sensitive to heat. This is why PWHT is *not* recommended by the AWS (clause 3.14) [8] for quenched and tempered steel and cold work hardened steel, despite tempering is necessary in manufacturing quenched and tempered steel. Therefore, cautions must be paid when designing the heat treatment solution for high strength steel structures and welded connections.

The main objective of this paper is to investigate the potential effects of PWHT on the reheated, quenched and tempered (RQT) grade S690 high strength steel welded connections. In the first phase of this study, a special welding procedure was designed to manufacture some welding affected coupon specimens. Following the recommendations of PWHT provided by the AWS structural welding code for steel [8], PWHT with different holding temperatures and holding times were conducted. Through the subsequent mechanical property tests, the effects of the PWHT methods were evaluated. The second phase of this study investigated the effect of PWHT on the residual stress level of four Y-shape plate-to-plate (Y-PtP) RQT S690 joints and the tensile behavior of nine T-stub RQT S690 joints. The hole drilling method was employed to measure the residual stress distribution near the weld toe of the

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Table 1
Mechanical properties of RQT-S690 steel.

	f_y (MPa)	f_u (MPa)	E (GPa)	Elongation (%)
RQT-S690 (8 mm)	769.0	849.8	206.5	14.7
RQT-S690 (16 mm)	745.2.0	837.8	208.9	14.5
EN 10025-6 S690Q/QL (3 mm ≤ t ≤ 50 mm)	690	770–940	–	14
S355J2H	410	535	208.4	30.2

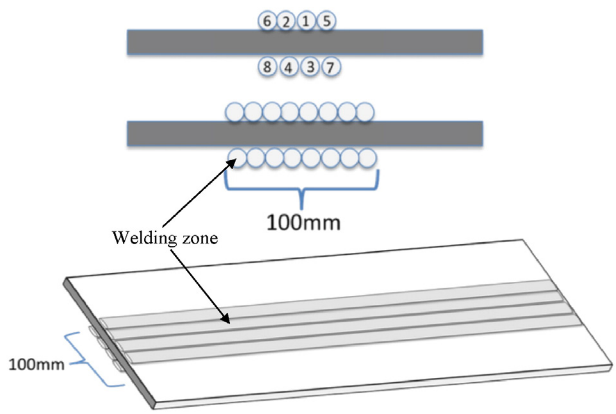

Fig. 1. Welding procedure for the fabrication of welding affected coupon specimens.

Fig. 3. Grinding machine with water cooling system.

Y-shape PtP joints and the tensile performance of the T-stub joints was examined by using a specially designed and fabricated test set-up.

2. PWHT for high strength steel

2.1. Material used

The high strength steel studied in this research is a reheated, quenched and tempered structural steel plate in grade S690. The reheated, quenched and tempered technology is essentially a refined quenching and tempering technology. In general, reheated, quenched and tempered steel plates exhibit better homogeneity in through-thickness mechanical properties compared with traditional directly quenched and tempered steel plates. The mechanical properties of the 8 mm and 16 mm RQT-S690 plates obtained by standard coupon tensile test are shown in Table 1 and are compared with the corresponding standard EN 10025-6 S690Q/QL [9] and the common S355J2H steel. From Table 1, it can be seen that this material has superior strengths compared to normal strength steels. The actual yield strength of RQT-S690 is more than 180% of the yield strength of S355J2H steel.

2.2. The PWHT process

Generally, the PWHT processes in this study were designed based on the recommendations provided by the AWS with amendments that are probably beneficial for RQT-S690 and suitable for the available laboratory equipment. The common heat treatment temperature for normal strength steels ranges from 600 °C to 650 °C. However, the allowable maximum heat treatment temperature for quenched and tempered steels is 600 °C as specified by the AWS [8] in consideration for the deterioration of mechanical properties after heating and cooling down. In heat treatment for steels, the maximum holding temperature and the holding time at the maximum holding temperature are the two most important factors that would influence the final mechanical properties of the steel under treatment [10]. A reduced temperature with longer holding time may lead to the same heat treatment result of a higher temperature with shorter holding time. Note that even the reduced 600 °C holding temperature is not a safe limit for heat treating for RQT-S690 weldment since it is proven that maintaining at 600 °C for just 10 min would be enough to introduce noticeable changes to the mechanical properties of RQT-S690 base metal [11–13]. Therefore, in this study, additional reduced temperature

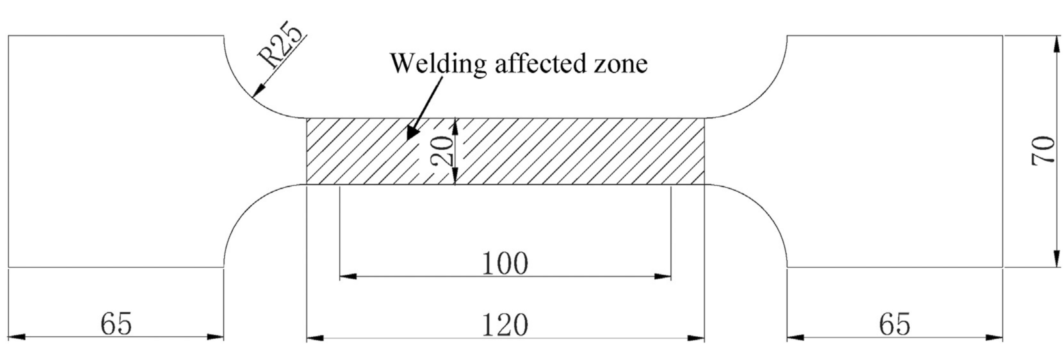

Fig. 2. Welding affected zone on the final coupon specimens.