Journal of Constructional Steel Research 150 (2018) 76–86

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Effect of welding and complex loads on the high-strength steel T-stub connection

Fei Fei Sun [a,b], Xuan Yi Xue [b,*], Yong Xiao [b,c], Yü Min Le [b], Guo Qiang Li [a,b]

[a] State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, Shanghai 200092, China
[b] College of Civil Engineering, Tongji University, Shanghai 200092, China
[c] Chongqing Steel Structure Industry Limited Company, Chongqing 400000, China

ARTICLE INFO

Article history:
Received 12 June 2018
Received in revised form 30 July 2018
Accepted 1 August 2018
Available online xxxx

Keywords:
High-strength steel
T-stub
First yield resistance
Heat affected zone
Combined axial and shear loads

ABSTRACT

After welding, a heat affected zone (HAZ) is formed in the area near a weld toe. The main microstructure is composed of high-strength steel (HSS) that is not stable at high temperatures. Therefore, it is necessary to investigate whether EC3 formulae based on examining a mild steel T-stub can be used to design an HSS T-stub. In the study, an experiment with two groups of Q690 T-stubs was performed. The results indicate that the EC3 formulae cannot be directly used to design the HSS T-stub. The effect of HAZ was further investigated by performing a finite element analysis (FEA). With respect to the specimens in the study, the factor χ_{HAZ} that represents the effect of HAZ is quantified by using the results of the experiment and FEA. The modified EC3 method2 was validated to accurately predict the first yield resistance of HSS T-stub. The T-stub is subjected to combined axial and shear loads. The relation between transversal and axial displacements of the T-stub under combined axial and shear loads was established. The effect of combined axial and shear loads on the connection behavior of the HSS T-stub was examined through the FEA. The result shows that the ductility of the T-stub under combined axial and shear loads is lower than that of the T-stub under axial load. We introduce a factor χ_{CL} to propose a formula to predict the first yield resistance of HSS T-stub by considering the effect of combined axial and shear loads.

1. Introduction

Structural steel is one of the most popular construction materials employed in structural engineering due to its high strength, high stiffness and ductile properties, [1]. Given the rapid advancements in thermal and mechanical processing procedures for structural steel production, high-strength steel (HSS) is increasingly used in recent years [2]. In several structural joint applications, the T-stub is the important component. The T-stub consists of a flange and a web by welding. With respect to conventional steel plates, it is suggested that, if the width of the soft zone does not exceed 25% of the plate thickness, local softening does not necessarily impair global strength due to the constraints of the stronger weld metal and unaffected base metal [3]. However, the assumption is questionable when applied to the HSS. This is because their main microstructure constituents including martensite and bainite are not stable at high temperatures [4]. Several studies demonstrated that it is not possible for quenched and tempered HSS steels to achieve high deformation capacity [5–7]. Furthermore, their mechanical properties are increasingly susceptible to heat [8]. Hence, the heat inputs of welding on tensile performance of HSS T-stub is important. Zhao indicated that the plastic resistances of HSS T-stub were generally lower than the predictions yielded by both the yield line method and the EC3 [9] equations. Potentially, the aforementioned strength reduction can be caused by heat inputs during welding that altered the HSS mechanical properties [10]. In order to compensate for the aforementioned adverse effects, a reduction factor is proposed to modify the EC3 formulae [11].

The traditional T-stub connection consists of two T-stubs welded or bolted to the beam and column flange [12]. This type of connection is popularly used in steel structures due to its high flexural resistance as shown in Fig. 1. With respect to the top T-stub, the deformation consists of axial and transverse deformation, thereby indicating that the T-stub is subjected to the joint effect of shear and axial loads. However, most studies on the T-stub traditionally focused on tensile behavior [13, 14]. It is questionable as to whether the tensile behavior is same as the tensile-shear behavior.

The main objective of the study involves investigating the effect of HAZ and combined axial and shear loads on the connection behavior of HSS T-stub. In Section 2, Q690 T-stub tensile behavior was investigated through an experimental method. In Section 3, the first yield

* Corresponding author.
E-mail address: xuanyixue@tongji.edu.cn (X.Y. Xue).

https://doi.org/10.1016/j.jcsr.2018.08.002
0143-974X/

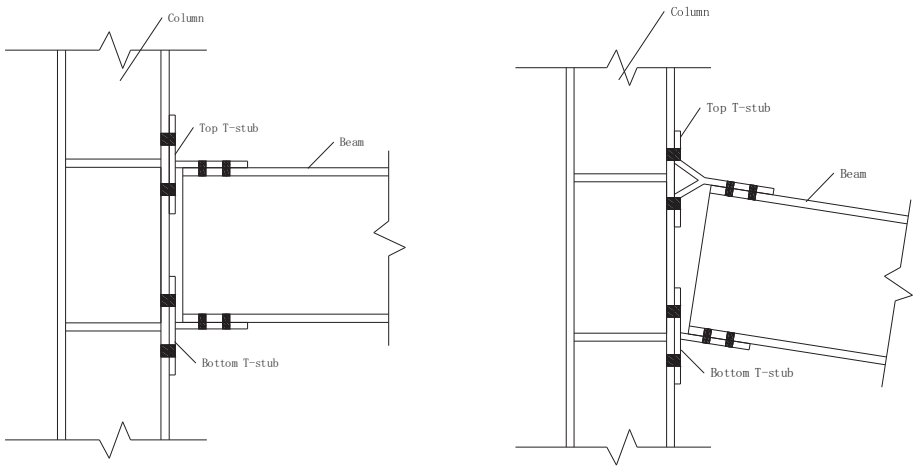

Fig. 1. Traditional T-stub connection.

resistance was obtained based on the test result of the Q690 T-stub and was compared with the predictions from the EC3 formulae. The difference between the collapse behavior of HSS T-stub and mild steel T-stub was investigated. In Section 4, the finite element modelling method was introduced by considering the effect of HAZ. The effect of HAZ was investigated through numerical methods. Based on the results of the experiment and FEA, the factor χ_{HAZ} was quantified to facilitate the modified EC3 methods. In Section 5, the effect of combined axial and shear loads on the HSS T-stub was investigated through numerical methods. A factor χ_{CL} was proposed to consider the effect of combined axial and shear loads on the first yield resistance.

2. Experimental investigation

2.1. Material properties

In the study, Q690 HSS and ER50 weld are selected to construct the T-stub specimen. The thickness of HSS plate used in the experiment is 16 mm. Based on a standard coupon tensile test for Q690 and ER50, the stress-strain curves and mechanical properties are shown in Fig. 2 and Table 1, respectively. The bolt used in the test corresponds to 10.9 grade high strength bolts M20. The mechanical properties of bolts are as follows: $f_y = 994$ MPa, $f_u = 1202$ MPa, and an elongation capacity of 15.2%. Additionally, HSS is different from mild steel since it exhibits poor tolerance to high temperature [15]. As indicated in a study by Sun [16], the effect of welding on the Q690 material properties is important. The material mechanical properties of the HAZ based on the study by Sun are shown in Table 1 and form the basis to perform the FEA considering influence of the HAZ.

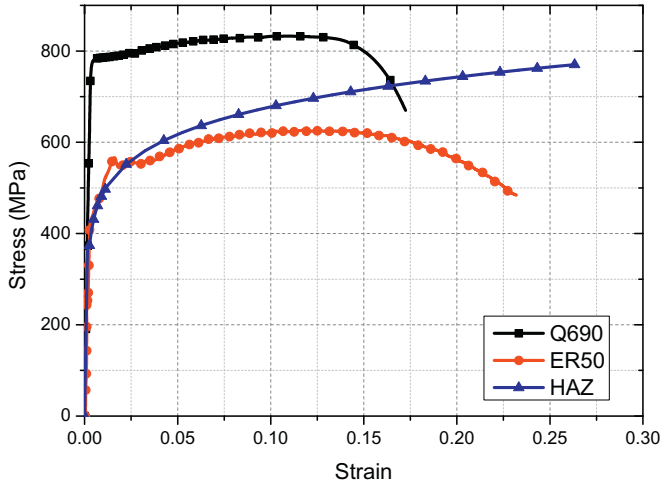

Fig. 2. Stress-strain curves of Q690, ER50, and HAZ.

2.2. Specimen fabrication

There are two groups of specimens, and each group consists of three specimens. Each specimen consists of two same T-stubs connected by four high strength bolts as shown in Fig. 3. The geometric dimensions of the specimen are listed Table 2. Shielded metal arc welding (SMAW) is employed. When compared to the other common welding methods, SMAW is more "friendly" to Q690 steel, which corresponds to martensite-based HSS due to its low heat input and exhibits a lesser effect on the HAZ [17]. In EC3, in order to estimate the design resistance of T-stub joints, three failure modes, namely (1) complete yielding of the flange, (2) bolt failure with yielding of the flange, and (3) bolt failure are identified [9]. In order to investigate the effect of HAZ on the connection behavior of HSS T-stub, all specimens are controlled to fail during the complete yielding of the flange.

2.3. Loading equipment and test procedure

A servo-hydraulic universal test machine that exhibits a maximum loading capacity of 2000 kN is used to perform the tensile tests for the

Table 1
Mechanical properties of the HSS plate and weld.

Material	f_y (MPa)	f_u (MPa)	Elastic modulus E(GPa)	Elongation after fracture (%)
Q690-HSS	782	832	236.9	19
ER50-Weld	400	627	224.9	27
HAZ	374	770	236.9	19

Table 2
Geometric dimensions information of T-stub specimen.

Group	h_w (mm)	t_w (mm)	n (mm)	m (mm)	e (mm)	p (mm)	t_f (mm)	h_f (mm)
T1	200	16	40	75	30	60	16	12
T2	200	16	60	90	30	60	16	12