Journal of Constructional Steel Research 126 (2016) 50–62

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Effects of corrosion on surface characterization and mechanical properties of butt-welded joints

Shanhua Xu, Hao Wang *, Anbang Li, Youde Wang, Lei Su

School of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China

ARTICLE INFO

Article history:
Received 16 March 2016
Received in revised form 2 July 2016
Accepted 4 July 2016
Available online xxxx

Keywords:
Pitting corrosion
Butt-welded joints
3D profile measurement
Corrosion characterization
Mechanical properties
Numerical simulation

ABSTRACT

The purpose of this study is to investigate the changes in surface morphology and mechanical properties for carbon steel butt-welded joints by ageing in salt spray environment. The corrosion characterizations of the base metal, heat-affected zone and weld metal for the butt-welded joints were tested by employing a 3D profile measurement technology, the results showed that the pitting geometrical parameters of all three zones had a similar time-dependent evolution rule, namely mean pit depth, maximum pit depth and volume-box parameter all increased with the increasing exposure corrosion time, while pitting aspect ratio decreased. In addition, it should be noted that the pitting corrosion in the heat affected zone was more severe than that in the other two zones. Tensile tests of the corroded butt-welded joint specimens were performed, the results had shown that the strength, ductility and strain hardening of the corroded butt-welded joints decreased as the degree of pitting corrosion increased. In particular, compared with the corroded base metal specimens with the same conditions, a more significant reduction of the tensile ductility for butt-welded specimens was observed. Besides, the reasons for this above degradation phenomenon were analyzed by using the numerical simulation methods.

1. Introduction

Welding as one of the most important connection form for steel infrastructure, has been widely used in the production and assembly of structural components. Anti-fatigue performance and mechanical properties of welded joints are generally affected by many factors, including initial defects, weld geometrical features, strength mismatch, stress concentration, temperature and residual stresses [1–8], which frequently determine service life of the steel weld structures. However, for some weld steel structure working in a condition of aggressive corrosion environment, such as industrial buildings, bridges and marine structures, fracture and fatigue damage due to serious corrosion in weld zones are the main threat to structure service reliability and safety. In percent, although many previous papers have investigated the corrosion behaviors of weld joints in different environment, and have demonstrated that the resistance of different zones to corrosion generally depend on metal composition and grain structure in each of the base metal, the HAZ and the weld metal [9–14], there is relatively little quantitative information about time varying trends of pitting geometrical features for the different zones of welded joints, as well as the effect of pitting damage on mechanical properties and fracture behaviors of welded joints.

In neutral salt spray environment, pitting corrosion is known to be one of the major corrosion forms affecting the integrity of steel structures, compared with general corrosion, the irregularity of corroded surface induced by pitting corrosion is the bigger threat to fracture initiation or crack nucleation of corroded components [15,16], thus, a good modeling of the longer-term pitting corrosion behavior is important for estimating the loss of structural integrity [17,18]. Pidaparti et al. [19] investigated the profile change of a single pit during the corrosion process. Melchers [20] and Wang et al. [21] proposed the model of the maximum pit depth and the model of pits ratio respectively. Lv et al. [15] and Walde and Hillberry [22] discussed the evolution rule of area-box parameters and surface pitting area with the increasing exposure time.

The information related to the morphology of pitting corrosion damage is deservedly identified as the most important data because it directly reflects the corrosion features of the concerned structures. At present, in order to characterize the corrosion features and quantify the extent of pitting corrosion, several physical probe techniques have been proposed and applied to obtain the pitting contour data, for example SEM [23], AFM [24] and X-ray tomography [25,26]. In addition, an improved method has been described by Holme and Lunder [27] for obtaining accurate 3D data of surface morphology of corrosion pits by using a White light interferometry instrument.

In the present article, 3D profile measurement technology was used to obtain the 3D surface morphology data of pits in the base metal, the HAZ and the weld metal. Parameters, such as, mean pit depth, maximum pit depth, aspect ratio and volume-box, were introduced to describe the evolution rule of pitting corrosion in the three different zones, with the increasing exposure corrosion time. Tensile tests of the butt-welded joint and the base metal specimens were performed

---

* Corresponding author.
E-mail address: wh19881218@126.com (H. Wang).

http://dx.doi.org/10.1016/j.jcsr.2016.07.001

in order to investigate the effects of pitting corrosion damage on the mechanical properties of the two types of corroded specimens. In addition, a series of nonlinear finite element analyses were applied to clarify the reasons of ductile degradation for the two types of corroded specimens due to pits.

2. Experimental procedure

2.1. Material and specimen preparation

The base material used in this study is a 235 MPa grade Chinese structure steel, namely Q235 steel. The plates were first machined into 2000 × 200 × 10 mm rectangular plates to serve as the weld blanks. Then two plates, with a single V-groove joint between them, were welded with complete joint penetration (CJP) by CO_2 GMAW procedure using ER50-6 welding wire as a filler material, based on the standard of JGJ81-2002 [28]. Finally, all butt-welded specimens, with the size of 400 × 80 × 10 mm, were extracted from the above welded plates and cut out parallel to the rolling direction of sheet, as shown in Fig. 1. Chemical compositions for the base and weld materials are specified in Table 1.

2.2. Accelerated corrosion experiment

Neutral salt spray accelerated corrosion tests were conducted to obtain the corroded butt-welded specimens, based on the standard of GB/T 10125-2012 [29] and GB/T 24517-2009 [30]. Where, the NaCl solution concentration was 50 mg/L, the PH value was 6.2–7.2, the diameter of the nozzle and the rate of mist spray of the spraying equipment were 0.5 mm–1.5 mm and 0.5–1.5 L/(min·m^2), respectively. The specimens were divided into 5 groups for corrosion, each group containing six standard specimens and one specimen without weld reinforcement. A group of corrosion-free specimens was also used as a control for tensile properties studies. All specimens for corrosion were placed individually on an exposure test fixture which parallel at an angle of 45° with regard to the vertical direction, as shown in Fig. 2. They were sprayed for 30 min with NaCl solution 4 times a day and rotated every day to provide uniform exposure to the salt spray. After exposed for 1, 2, 3, 4 and 6 months, respectively, the specimens were retrieved and cleared away the corrosion products with dilute hydrochloric acid and distilled water, and then kept in CaO desiccator until the scanning tests and tensile tests. In order to achieve the mass-loss ratios of the corroded specimens, they were weighed with analytical balance before and after the accelerated corrosion tests. Besides, in order to obtain the nominal stress of corroded specimens after tensile tests, the average depths at both ends of the specimens and HAZ were measured respectively by using Vernier caliper before and after the accelerated corrosion tests.

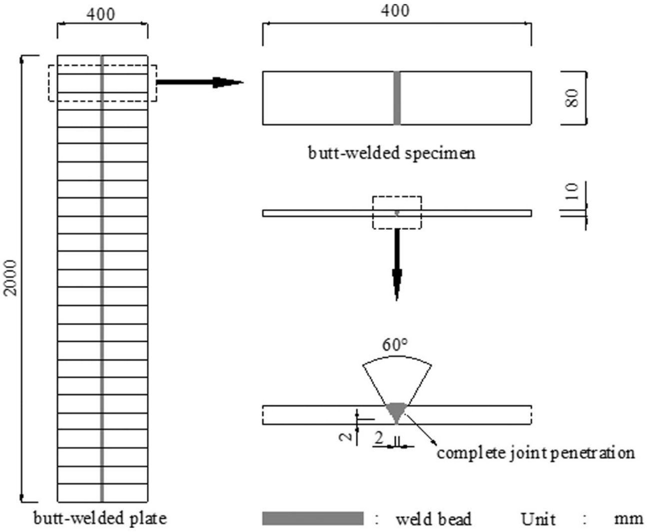

Fig. 1. Dimensional detail of specimens for corrosion.

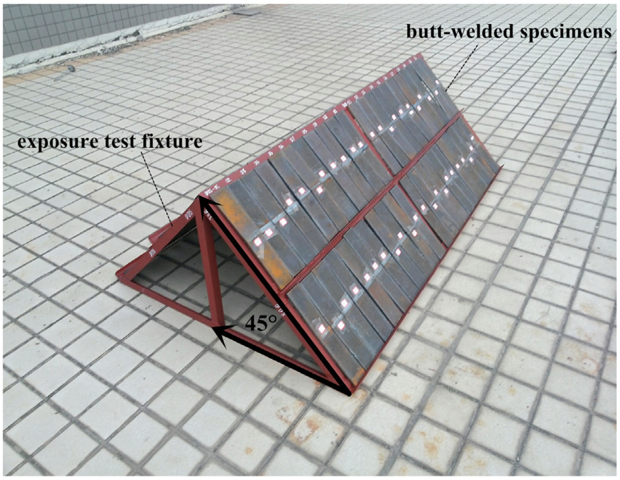

Fig. 2. Condition of accelerated corrosion experiment.

2.3. Corroded surface profile measurements

To obtain the geometric morphology characterization of pitting corrosion in the three different zones of butt-welded joints, avoiding the influence of the nonuniform weld reinforcement, the scanning test specimens were fabricated from the only butt-welded specimen without weld reinforcement in each group. Then the 3D surface profiles of both sides of five scanning test specimens were measured by using a non-contact PS50 3D profiler produced by NANOVER. The intervals of measurement data are 50 μm and 50 μm in X and Y directions respectively. The schematic of the measurement area is shown in Fig. 3. It should be noted that the measurement area of each scanning test specimen, on both sides, was divided into the weld metal (WM), the heat affected zone (HAZ) and the base metal (BM) based on the extent of such zones visible by physical examination of corrosion-free samples and some relevant regulations of JB 4708-2000 [31].

2.4. Tensile tests

In order to investigate the mechanical properties of the different types of specimens after corrosion, two types of tensile test specimens were machined from the butt-welded specimens: (1) the butt-welded joint containing the weld in the center of the gauge length; (2) the base metal specimen containing the weld in the edge of the clamping position and wiping out the weld reinforcement. The sizes of the dogbone specimens were considered to be consistent with GB/T 2651-

Table 1
Chemical compositions of the base metal and the weld metal used (wt.%).

Material	C	Si	Mn	S	P	Cr	Ni	Cu
Q235	0.18	0.28	0.34	0.04	0.04	0.02	0.02	0.02
ER50-6	0.06	0.90	1.50	0.025	0.025	0.15	0.15	0.5