Materials and Design 36 (2012) 233–242

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of microstructure on mechanical properties in weld-repaired high strength low alloy steel

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ARTICLE INFO

Article history:
Received 20 September 2011
Accepted 8 November 2011
Available online 15 November 2011

Keywords:
D. Welding
F. Microstructure
G. Fractography

ABSTRACT

To understand the effect of microstructure on mechanical properties of weld-repaired high strength low alloy (HSLA), as-received and weld-repaired HSLA with and without buffer layers (BLs) were prepared. Microstructure analysis was carried out using optical microscope and SEM, and mechanical properties were measured by Vickers hardness test and fatigue test.

The fatigue resistance of weld-repaired HSLA without BL was deteriorated with comparing to parent metal (PM). Meanwhile, Vickers hardness (VH) showed an obviously reduction in the melted parent metal (MPM), which was due to formation of predominately block ferrite. For the weld-repaired HSLA with BL, the VH and fatigue resistance increased with the incorporation of 4 mm BL, which was mainly due to formation of lath ferrite and fine-grained pearlite and bainite. When BL thickness increased to 10 mm, the VH and fatigue resistance decreased, which was because the thick BL diluted the MPM. VH number from low temperature (below melting point) heat affected zone (HAZ) fluctuated, but had a little scatter. However, the fatigue crack growth rate from HAZ was not obviously affected by the welding as comparison with the PM.

1. Introduction

High strength low alloy (HSLA) steels with excellent strength characteristics have been widely used in various applications including cars, trucks and cable-stayed bridges. The strength of HSLA steels comes from their microstructure. Strength is increased by: increasing the amount of pearlite and bainite, increasing the fineness of the grains structure, increasing the amount of hard precipitate [1].

Wear damaged sections of supporting structures manufactured from HSLA are often weld-repaired or filled by similar metals through welding [2], or weld deposited by hard-facing alloys to provide a wear resistant surface for structural base materials. However, HSLA steels are hard to weld repair and special care is required because of their high strength [3,4]. Furthermore, the welding joints of HSLAs are often become the weak link in mechanical testing due to softening in the welding joints. To understand the detrimental influence of the welding on mechanical properties of welded HSLAs, a number of studies have been performed to assess the effects of chemical compositions, metallographic structure, welding procedure and heat treatment (pre- and post-).

With increasing of the copper content in weld metal, microstructure became finer in all zones of the weld metal, hardness and tensile strength increased, but Charpy impact toughness decreased [5]. The increase of manganese content was useful to refine and homogenize the weld microstructure, and the increase of titanium content in the range of 0.02–0.08% increased the acicular ferrite for the API 5L-X70 (HSLA) with moderate manganese content [6].

The amount of M-A constituent in coarse-grained HAZ of HSLA influenced the toughness value, and voids and micro-crack initiated at the M-A constituents [7]. The high-toughness low-carbon bainite in the HAZ of EH36 TMCP decreased fatigue crack growth rate, and post weld heat treatment was unnecessary [8]. Due to the coarse upper bainite, the weld metal was the weakest link in terms of toughness and fatigue resistance [9].

The fusion zone of laser welded HSLA, near to the interface of fusion zone and HAZ, was the weakest link of fatigue behavior [10]. Under the condition of gas metal arc welding, the high hardness welds (over 248HV) of HSLAs (API 5L X70 and X80) increased the resistance to sulfide stress cracking at low H_2S concentrations [11]. Welded HSLA is often prone to softening in HAZ, which causes a weak link in mechanical properties [12]. However, HAZ of HSLA showed lesser softening in low heat input welding than in high heat input welding, and post weld heat treatment about A_{C3} and

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0261-3069/$ - see front matter
doi:10.1016/j.matdes.2011.11.016

external cooling were beneficial to reduce the tendency for softening in HAZ [13]. Reducing cooling time decreased the austenite grain size and volume fraction of M/A constituent, thus increased the toughness of HAZ of HSLA [14]. The cooling rate changed the microstructure in weld metal was also reported by Ghosh, et al. [15]. In the coarse-grained region of HAZ, the microstructure consisted of predominantly bainite packets and a small proportion of acicular ferrite was more stable than bainite during tempering [16].

Submerged arc welded joint of HSLA (14HNMBCu grade S690Q) had higher resistance to hydrogen degradation in sea water environment than shielded metal arc welded joint [17].

With different emphases to those aforementioned studies on welded HSLA steels, buffer layer between weld metal and parent metal was introduced to increase the fatigue resistance of welding joint in this paper. The primary objective of the present study was to investigate the metallographic structure of extensively weld-repaired HSLA steel with or without a buffer layer, and its influence on the mechanical properties of welding joint, which has not been systematically studied as shown in previous literatures.

2. Experimental procedure

2.1. Material and specimen

The substrate material used for the present investigation was a HSLA steel (Bisplate80-parent metal PM) with a low carbon content. The weld metal (WM) and buffer layer (BL) were SmoothCor™ 115 and SmoothCor™ 70C6, respectively, thus effectively forming a welding joint together with PM with different strength characteristics. Flux cored arc welding was employed to perform the extensive welding repair, while 100% CO_2 was used as the shielding gas. The core wire had a diameter of 1.2 mm, and electrode stick-out was 20 mm. A constant current power source (230A, 27 V) with DC + polarity was used in all cases (WM, 4 and 10 mm BLs).

The chemical compositions and mechanical properties of PM, WM and BL are listed in Tables 1 and 2. Extended-Compact Tension (E-CT) specimens with machined through-the-thickness notches were machined following the specifications of ASTM E647 (23) [18]. The specimens were divided into four groups: (1) as-received HSLA, (2) weld-repaired HSLA without BL, (3) weld-repaired HSLA with 4 mm BL, and (4) weld-repaired HSLA with 10 mm BL. Dimensions of the E-CT specimens are shown in Fig. 1, and all dimensions are in mm.

2.2. Microstructure study

The four groups of E-CT specimens, (1) as-received HSLA specimens, (2) weld-repaired specimens without BL between the WM and PM, (3) weld-repaired specimens with 4 mm BL, and (4) weld-repaired specimens with 10 mm BL, were mechanically polished and etched using 4% nital solution for a few seconds to reveal their microstructures. The microstructures of the four groups of E-CT specimens were examined in detail by inverted optical microscope (JVC CMM-22E). The macrographs of the weld-repaired specimens' surfaces after polishing and etching were obtained using professional digital camera.

The micro-structure of fatigue surfaces of tested specimens associated with various regions in as-received and welded specimens, especially in MPM and BL + MPM, were observed in detail by a scanning electron microscopy (SEM).

Table 2
Mechanical properties of PM, WM and BL.

Series	Tensile properties			
	Yield strength (Mpa)	Tensile strength (Mpa)	Elongation (%)	Impact energy (J)
PM	690 min	790 min	18 min	40 min (−20 °C)
WM	690 min	760 min	17 min	50 min av. (−51 °C)
BL	410 min	490 min	22 min	27 min av. (−29 °C)

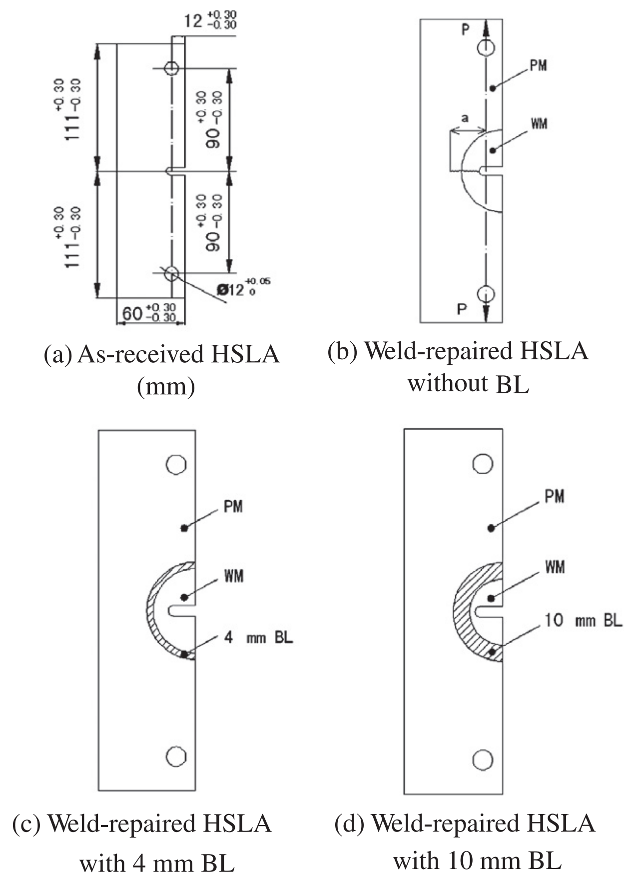

Fig. 1. Dimensions of E-CT specimens.

Table 1
Chemical compositions of PM, WM and BL.

Series	Element (wt.%)								
	C	Si	Mn	Cr	Mo	Ni	P	S	B	CE(IIW)
PM	0.18	0.20	1.40	0.20	0.20	–	0.01	0.003	0.0010	0.50
WM	0.06	0.30	1.40	0.22	0.44	2.29	–	–	–	0.58
BL	0.03	0.59	1.66	–	–	–	–	–	–	0.31

CE(IIW) = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5.