Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 507−513
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effect of filler metal on microstructure and mechanical properties of manganese−aluminum bronze repair welds

M. R. MIRZADEH RAHNI, B. BEIDOKHTI, M. HADDAD-SABZEVAR

Materials and Metallurgical Engineering Department, Faculty of Engineering,
Ferdowsi University of Mashhad, Mashhad, Iran

Received 1 March 2016; accepted 2 November 2016

Abstract: The repair welding of UNS C95700 manganese−aluminum bronze plates was done using different filler metals. The microstructure and mechanical properties of welds were studied. The main microstructural constituents were α, β and κ phases with different morphologies. The addition of manganese decreased the percentage of α phase in the microstructure of weldments from 80% (Mn-free weld) to 57% (12.5% Mn weld, mass fraction). The morphology of κ phase was lamellar in high nickel specimens and it was changed to a globular morphology for high manganese welds. Although the application of high manganese filler metal yielded the higher tensile and bending strengths of weldment compared with the weld using high nickel filler material, the optimum mechanical properties of repair welds were obtained using a non-alloy filler material (ERCuAl-A2) for the underlay and high manganese filler metal (ERCuMnNiAl) for filling passes. This weld presented an increase of 39% in tensile strength compared with the base metal, and no cracking was observed after bending test.

Key words: manganese−aluminum bronze; welding; filler metal; microstructure; mechanical properties

1 Introduction

Manganese−aluminum bronze (MAB) and nickel−aluminum bronze (NAB) alloys have high mechanical properties and erosion−corrosion resistance to seawater [1,2]. These alloys are often used in marine industries. Although MAB and NAB are similar in many features, MAB usually has better mechanical properties and lower density [3]. NAB has a better corrosion resistance than MAB, especially after annealing [4]. Furthermore, MAB does not show a brittle temperature range and its lower melting point is useful for welding [3]. FULLER et al [5] found a region of low ductility in the heat-affected zone (HAZ) of NAB fusion weldments.

It has been shown that the microstructure of manganese−aluminum bronze is a mixture of α (FCC Cu-rich solid solution), β (BCC) and intermetallic precipitates with different morphologies (κ phase) [6,7]. During the solidification of aluminum bronzes, the BCC β phase transforms to the FCC primary α phase with a Widmanstätten morphology and γ_2 (eutectoid reaction) [7−12]. According to the results of JAHANAFROOZ et al [13], Fe_3A1 particles are formed in β phase and then they precipitate in α phase during cooling.

It has been reported that different morphologies of κ phase (globular, lamellar, etc) could also form in α and β phases at 800−930 °C [5]. The percentage of α phase within the microstructure of aluminum bronze could be increased by the additional of Fe. Furthermore, the addition of Fe to the bronze promotes the formation of κ precipitates and reduces the amount of brittle γ_2 phase. In fact, Fe shifts the formation of γ_2 phase to the higher amount of Al [14]. NI et al [15] claimed that the existence of Fe in the composition of bronze improved wear resistance and fatigue strength.

The increased Ni content of bronze decreases the percentage of β and γ_2 phases and encourages the formation of κ phase [16]. Although the solubility of Ni in bronze is the important factor, the Fe/Ni ratio has a great influence on the microstructure of alloy. Increasing Fe/Ni ratio can change the morphology of κ phase from lamellar to globular. The shape and size of these precipitates alter the mechanical and corrosion properties of bronze alloys. The interface of α and lamellar κ phases is a favorite path for crack propagation [17], and κ precipitates are preferentially corroded in acidic environments [18].

Corresponding author: B. BEIDOKHTI; Tel: +98-51-38805145; Fax: +98-51-38807182; E-mail: beidokhti@um.ac.ir
DOI: 10.1016/S1003-6326(17)60057-8

Large cast aluminum bronze components are usually fabricated using welding processes because of some difficulties in making the mold; and besides, fusion welding, especially gas tungsten arc welding (GTAW) process, is often applied to repairing casting porosity of aluminum bronze parts such as damaged ship propellers. The mechanical properties of manganese−aluminum bronze weldments depend on the chemical composition of weld and thermal cycle. The chemical composition of filler materials is usually similar to that of the base metal; however, the nickel-based filler metals have also been proposed for welding of copper alloys [19]. Although it is believed that the effect of thermal cycle and heat treatment is negligible in Al-bronzes containing 8%−9.5% Al and less than 2% of other elements [20], the process is more complicated in the case of high alloy bronzes.

In repair welding, the mechanical properties and corrosion resistance of the deposited area are a great concern. It has been shown that the weld zone (WZ) could yield better erosion resistance than the heat-affected zone (HAZ) and the base metal after repairing [21]. TANG et al [22] improved the erosion resistance of MAB by the application of laser surface melting. SABBAGHZADEH et al [23] claimed that the overall corrosion resistance of gas tungsten arc welded bronze parts was not deteriorated by welding process. Although the microstructural refinement by friction stir process (or friction stir welding) could improve the corrosion resistance of bronze parts [24], it is believed that the erosion−corrosion resistance could be decreased [25].

Although several researches have focused on the microstructure evolution of aluminum bronze components, their repair welding has not been systematically studied. The mechanical behavior of repair welds is a great practical concern in shipping industry. The aim of the present work was to investigate the effect of filler metal combination on the microstructure and mechanical properties of manganese−aluminum bronze repair welds.

2 Experimental

The 200 mm × 100 mm × 30 mm plates of UNS C95700 manganese−aluminum bronze were used as the base metal. The gas tungsten arc welding (GTAW) was applied using different filler metals. The compositions of the base and filler materials are presented in Table 1. A groove with an angle of 70° and a depth of 15 mm was used to duplicate the repair welding condition (Fig. 1). The welding parameters were constant for all specimens. The welding current, arc voltage, wire diameter and shielding gas were chosen as 185 A, 24 V, 2.4 mm and 99.999% argon with the flow rate of 12 L/min, respectively. The preheating and inter-pass temperatures were 175 and 245 °C, respectively. The sequence of the welding passes is observed in Table 2. The post-weld heat treatment (PWHT) was done under conditions of 340 °C and 90 min. The temperatures of preheating and PWHT were controlled using appropriate thermal chalks.

A Zwick 250 kN universal testing machine was used for the mechanical tests. Both longitudinal and transverse tensile tests were conducted and subsize tensile samples were prepared according to ASTM E8 (the length of samples, gage length and width of reduced section were 100, 25 and 6 mm, respectively). Also, the three-point bending test was done to measure the bending strength of the welds (ASTM E290). The sizes of bending samples were 75 mm × 10 mm × 2 mm. The fracture stress of the three-point bending test can be obtained from Eq. (1):

$$\sigma=3PL/(2bh^2) \tag{1}$$

where P is the bending force, L is the length of the test span, h is the thickness of specimen, and b is the specimen width [26]. Vickers hardness testing was performed in a straight line 4 mm below the surface of the base material using a constant load of 10 kg. The distance between measurement points was 1 mm.

The metallographic sections were polished using different grades of emery papers and finally with an alumina suspension. Then, these sections were etched with 100 mL ethanol + 15 mL HCl + 5 g $FeCl_3$. An optical microscope and metallographic image processing (MIP) software were used to study the microstructure of weld sections. Further microstructural investigations were done by an LEO 1450 VP scanning electron microscope (SEM) linked to an EDS system.

Table 1 Compositions of base and filler materials

Material	Mass fraction/%											
	Mn	Al	Ni	Fe	Pb	Si	Zn	Sn	P	Cr	S	Cu
Base metal	13.0	7.2	2.7	3.4	0.04	0.8	0.01	0.01	0.02	0.05	0.02	Bal.
ERCuAl-A2	−	9.5	−	1.5	0.02	0.1	0.02	−	−	−	−	Bal.
ERCuNiAl	1.5	9.0	5.0	3.5	0.02	0.2	0.1	−	−	−	−	Bal.
ERCuMnNiAl	12.5	7.5	2.0	3.0	0.02	0.1	0.1	−	−	−	−	Bal.