Materials and Design 35 (2012) 303–309

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Effect of Ti on hot cracking and mechanical performance in the gas tungsten arc welds of copper thick plates

Li Yinan, Liu Xuesong, Yan Jiuchun *, Ma Lin, Li Chunfeng

State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, People's Republic of China

ARTICLE INFO

Article history:
Received 26 August 2010
Accepted 22 September 2011
Available online 29 September 2011

Keywords:
A. Ferrous metals and alloys
D. Welding
F. Defects

ABSTRACT

The new welding material – ERCuTi alloys filler metals were developed for gas tungsten arc welding (GTAW) of copper. The cracking susceptibility of the welds with ERCuTi and ERCu separately in GTAW of 10 mm copper thick plates was investigated. The formation causes of hot cracking was researched by using ERCu and the suppression mechanism of hot cracking when using ERCuTi alloy filler was proposed. It has been found that, when element Ti is added into the welding pool, the Ti will combine with O preferentially rather than Cu to generate TiO_2, which process can suppress the formation of Cu_2O. The hot cracking force and the hot ductility of the welds in brittle temperature range (BTR) could be improved effectively by adding Ti in filler metal compared with that of the welds without Ti. But the degree of addition of Ti (2–4 wt%) is critical when the susceptibility of cracking is to be suppressed. If the level is allowed to exceed 4 wt%, more low-melting point eutectics (β-$TiCu_4$ and $TiCu_2$) will be formed in the welds, and cracking susceptibility will be increased again. Results of mechanical properties tests show that although adding Ti increases the hardness and strength of the weld compared to the base metal, the impact ductility and the plastic properties are not decreased significantly.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

During the fusion welding of copper, atmospheric O_2 is ionized by the arc and oxygen ions diffuse into the welding pool [1]. The oxides of copper on the surface of the base metal are melted by the arc and absorbed into the welding pool. During the solidification of the weld metal, the oxygen combines with copper to form Cu_2O, and at 1065 °C the eutectics of Cu and Cu_2O form at the grain boundaries of the α-Cu [2]. This weakens the joining strength of the crystalline α-Cu because it has a low melting point, resulting in cracking of the weld metal. Hot cracking is a serious problem in fusion welding of copper because of the inevitable oxidation of the copper. The formation of eutectics in the weld metal is the key issue to reduce hot cracking in copper welds.

The use of ERCu as a filler in the fusion welding of copper is a well-established commercial practice [3]. Mn and Si are present in the filler to reduce the formation of copper oxides in the welding pool and thus to decrease the susceptibility of hot cracking. However, hot cracking is not usually suppressed completely by using ERCu when welding thicker copper plates. To address this problem, the most popular method is to preheat the base metal before welding [4,5], as preheating has the function of decreasing shrinkage strain of weld. Typically, although the required temperature varies with copper plate thickness, the copper should be preheated to over 300 °C [6]. However, the micro-cracks still exist in the welds because of the inevitable oxidation of the welding pool.

There are two factors to increase the cracking susceptibility of the welds. One is the metallurgical fundamental, the alloying elements aggregated at grain boundary form as the origination of cracking in welding of steels and aluminum alloys [7–9]. The other is mechanical performance, the hot ductility and hot cracking force of the welds in BTR is very low. Therefore adding one element in filler metal which has the function of de-oxidation and improving the high temperature mechanical performance in BTR is the basic solution for suppression of hot cracking in GTAW of copper. Element Ti is used as a de-oxidizer when casting low carbon high manganese steel [10,11]. The addition of TiB in aluminum alloys is known to prevent hot cracking [12]. Titanium metal has been used as a denitrider in copper filler metal to suppress nitrogen porosity in N_2-GTA welding of copper [13]. Moreover, element Ti has the ability to strengthen the CuTi alloys with the precipitation of intermetallic compounds [14,15].

In this paper, a CuTi alloy filler metal containing metallic Ti was developed specially for GTAW of copper thick plates. A rigid restraint cracking test was used to compare the cracking susceptibility of the filler metals with or without element Ti. A hot-tension test was performed to examine the hot cracking force and hot ductility of the welds made with different filler metals by using

* Corresponding author.
E-mail addresses: liyinan2004@163.com (L. Yinan), jcyan@hit.edu.cn (Y. Jiuchun).

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.09.050

GLEEBLE thermomechanical system as the data analysis could define and map the stress and temperature conditions leading to crack initiation [16]. The mechanism of elemental Ti suppressing hot cracking in GTAW of copper was analyzed. Moreover, the mechanical performance of the welds with Cu and CuTi alloy fillers was examined and compared.

2. Experimental procedure

A rigid restraint cracking test (GB13817-92) was used to evaluate the susceptibility of hot cracking. The samples of nominal size $250 \times 100 \times 10$ mm were welded by He-GTA welding without preheating, using ERCu, ERCuTi-2 and ERCuTi-4 as filler metals. Both macro- and micro-scale hot cracking were observed and the cracking rate was measured. The chemical composition of the filler metals are listed in Table 1.

Hot-tension test was preformed using a GLEEBLE 1500 thermomechanical simulator to examine the hot cracking force and hot ductility of the welds. The deposited metals made with ERCu and ERCuTi-2 separately were processed as round bar specimens (Φ6 mm) according the dimension showed in Fig. 1. A section about 30 mm long in center of the samples was heated to the molten state to simulate the conditions of welding course. A quartz tube, with a small longitudinal slot accommodating a thermocouple, was used to prevent molten metal from flowing and changing its shape. A peak temperature 50 °C higher than melting temperature was used to ensure the melting actually occurred. When cooling down to the testing temperature the specimens were held for 3 s to remain temperature stable. Then the tension was loaded along axial direction of specimen at the speed of 0.1 mm s^{-1}.

Cross-sections of welded joints were prepared for metallographic analysis by a standard polishing technique. The microstructures of the welded joints were examined by light microscopy (Olympus-PMG3), transmission electron microscopy (TEM, Philips CM12), a scanning electron microscope (SEM, S-570) equipped with an energy dispersive X-ray spectrometer (EDS, TN5500), and electron probe microanalysis (EPMA, JEOL-733). The tensile strength of welded joints was evaluated by using a tensile testing machine (Instron-5569).

3. Results and discussion

3.1. Hot cracking susceptibility of the welds made with ERCu, ERCuTi-2 and ERCuTi-4

The cracking rates of the welds made with the three filler metals (ERCu, ERCuTi-2 and ERCuTi-4) are shown in Table 2 by using a rigid restraint test. It was observed that the cracking rates with the ERCu filler metal are greater than 50%, but with ERCuTi-2 are nil, both at the surface and through the weld cross sections. This means cracking inevitably occurs under practical welding condition when using ERCu as the filler, while there is no cracking in the weld metals by filling ERCuTi-2. However, when using ERCuTi-4 filler, if the added Ti content exceeds 4 wt%, some microcracks will appear in welds.

Table 1
Chemical composition of the filler metals, wt%.

Filler metal	Cu	Sn	Mn	Si	Ti
ERCu	98.4	1.0	0.3	0.3	-
ERCuTi-2	98	–	–	–	2.0
ERCuTi-4	96	–	–	–	4.0

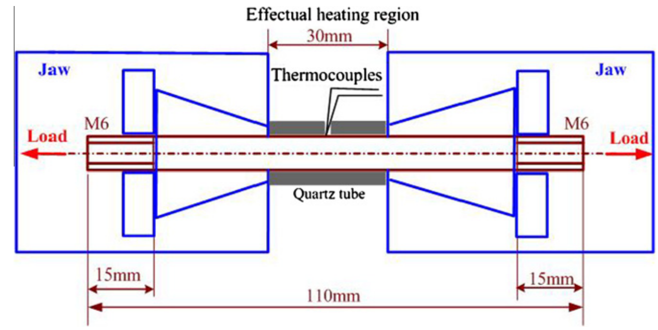

Fig. 1. Round bar specimen of GLEEBLE 1500 thermo-mechanical simulator.

Table 2
The variation of cracking rates of GTA welds with filler types, %.

Filler metal	Surface cracking rate	Cross section cracking rate
ERCu	51.3	83.3
ERCuTi-2	0	0
ERCuTi-4	0	6.5

3.2. Mechanical performance of the welds in BTR

In M. Li's paper, the hot tearing force was selected as evaluating the hot tearing resistance of Al–5% Cu–xY alloys during solidification. In A.B. Phillion's research, the tensile deformation experiment of semi-solid aluminum alloys to evaluate the susceptibility of hot tearing, and the hot tearing force and hot ductility were measured in this experiment [17,18]. In our research, two properties can be obtained from the hot-tension test: hot cracking force (F) and hot ductility (δ) to evaluation the mechanical performance of the welds in BTR. The hot cracking force of the simulated welds made with ERCu and ERCuTi-2 is shown in Fig. 2a. It is noted that the cracking force in BTR increased with decreasing testing temperature for these two welds. As the testing temperature decreases, the samples change from the liquids to solid state, thus the hot cracking force increases. This experiment phenomena is consistent with the experiment of Sun et al. In his research the hot force and hot ductility of niobium-bearing stainless steel decreased with the temperature increasing using the solidification cycle hot-tension test [19]. It is also noted that the cracking force of the welds made with ERCuTi-2 in BTR, ranged from 18.5 MPa to 41.0 MPa, is higher than that of the welds made with ERCu which range is 8.6–21.3 MPa. The hot ductility of the welds as the function of temperature is shown in Fig. 2b. It can be seen that the ductility of the welds made with ERCuTi-2 in BTR is much higher than that of the welds made with ERCu. The minimum ductility of the welds made with ERCu is 0.00261 at 1058 °C, while the minimum ductility of the welds made with ERCuTi-2 is 0.0479 at 990 °C, which is about 18 times of the welds with ERCu.

It is well known that the hot cracking force of the welds in BTR is the necessary condition of forming hot cracking and the deformation of the welds in BTR is the necessary and sufficient condition. The cracking susceptibility would be decreased with the increasing of cracking force and hot ductility of the welds in BTR. Compared the results of the welds with or without element Ti, the cracking force and the hot ductility of the welds in BTR is improved effectively by adding Ti in filler metal. One reason of adding Ti in CuTi filler metals to improve high-temperature mechanical performance is that element Ti has the ability to suppress the oxidation of the welding pool so as to improving the hot ductility in BTR. And the course of de-oxidation will be discussed later. The other reason is that element Ti has the ability to strengthen the

Download English Version:

https://daneshyari.com/en/article/830943

Download Persian Version:

https://daneshyari.com/article/830943

Daneshyari.com