Materials and Design 32 (2011) 3796–3802

Contents lists available at ScienceDirect

Materials and Design

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

The investigation of abnormal particle-coarsening phenomena in friction stir repair weld of 2219-T6 aluminum alloy

Bo Li, Yifu Shen *

College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, 29 Jiangjun Road, Nanjing 210016, PR China

ARTICLE INFO

Article history:
Received 17 January 2011
Accepted 11 March 2011
Available online 21 March 2011

Keywords:
A. Non-ferrous metals and alloys
D. Welding
F. Microstructure

ABSTRACT

The single-pass friction stir weld of aluminum 2219-T6 with weld-defects was repaired by overlapping friction stir welding technique. However, without any post weld heat treatment process, it was found that the phenomena of abnormal particle-coarsening of Al_2Cu had occurred in the overlapping friction stir repair welds. The detecting results of non-destructive X-ray inspection proved that not only one group of repair FSW process parameters could lead to occurrence of the abnormal phenomena. And the abnormally coarsened particles always appeared on the advancing side of repair welds rather than the retreating side where the fracture behaviors occurred after mechanical tensile testing. The size of the biggest particle lying in the dark bands of 'Onion-rings' was more than 150 μm. After the related investigation by scanning electron microscope and X-ray energy spectrometer, three types of formation mechanisms were proposed for reasonably explaining the abnormal phenomenon: Aggregation Mechanism, Diffusion Mechanisms I and II. Aggregation Mechanism was according to the motion-laws of stir-pin. Diffusion Mechanisms were based on the classical theories of precipitate growth in metallic systems. The combined action of the three detailed mechanisms contributed to the abnormal coarsening behavior of Al_2Cu particles in the friction stir repair weld.

1. Introduction

Invented by The Welding Institute (TWI) of UK [1], Friction stir welding (FSW) is a relatively novel solid-state jointing technique with potentially significant applicability to almost all aluminum alloy series [2,3], in particular 2XXX and 7XXX series classified as 'non-weldable' by conventional fusion welding methods. 2219-T6 aluminum alloy, which can be successfully friction stir welded [4–7], has a great potential for a wide range of aerospace applications with its high strength-to-weight ratio, good fracture toughness, superior cryogenic properties and excellent stress-corrosion resistance [8]. Al_2Cu is the major intermetallic phase in Al–Cu alloy 2219-T6, in which the strengthening precipitates are mainly metastable, plate-shaped coherent θ'' and semi-coherent θ' [9,10]. The hardening at room temperature is attributed to local concentrations of Cu atoms forming GPZs (Guinier Preston zones) [11]. Its precipitation sequence, or the evolution procedure of super saturated solid solution (SSSS), can be stated as

$$\alpha \rightarrow \alpha + \text{GPZs} \rightarrow \alpha + \theta'' \rightarrow \alpha + \theta' \rightarrow \alpha + \theta \qquad (1)$$

The strengthening or age-hardening mechanism in 2219 aluminum alloy can be explained in terms of obstacles to the motion of dislocations by θ'', θ' and parts of stable θ phase particles, which should be fine enough. Following the coarsening or growth of θ phase (Al_2Cu), the solid-solution strengthening effect of copper is reduced due to that coppers in matrix has partly moved into Al_2Cu particles. And the large-sized Al_2Cu particle has lost its obstacle function. Due to the special thermo-mechanism and the asymmetric forms of plastic metal-flow in the weld-zone during FSW process [12–14], the spatial distribution laws and the coarsening mechanisms of Al_2Cu particles have different characteristics in 2219 Al alloy FSW weld-zone partitions of stir-nugget zone (SNZ), thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) [5,6,15,16]. In addition, without any post weld heat treatment (PWHT) process, the max-size of stable θ phase (Al_2Cu) particles is no more than 20 μm in the whole single-pass friction stir (FS) weld of aluminum 2219-T6 [5,6].

As distinguished from fusion welding techniques, FSW joins metals below their melting point T_M [3]. Therefore, the whole thermal history of solid-stating FSW process contributes to avoid the metallurgical weld-defects, like hot-cracks and blowholes. But several types of FS-weld-defects (such as tunnel, void, porosity, surface groove, flash, 'S-curve', etc.) could occur due to some unsuitable process parameters [4]. However, the FS-weld-defects can always be repaired by the overlapping FSW technique to form a second-pass FS-weld on the original weld [17]. In the present work, the original defective FS-welds were repaired by an overlapping FSW process. However, it was found that the phenomenon of abnormal particle-coarsening occurred in the repair welds without

* Corresponding author. Tel.: +86 15050597986; fax: +86 2552112626.
E-mail addresses: yifushen_nuaa@hotmail.com, yifushen@nuaa.edu.cn (Y. Shen).

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.03.029