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ScienceDirect

Defence Technology 11 (2015) 166–173

www.elsevier.com/locate/dt

Microstructure and pitting corrosion of armor grade AA7075 aluminum alloy friction stir weld nugget zone – Effect of post weld heat treatment and addition of boron carbide

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Received 27 September 2014; revised 27 November 2014; accepted 15 January 2015
Available online 16 March 2015

Abstract

Friction stir welding (FSW) of high strength aluminum alloys has been emerged as an alternative joining technique to avoid the problems during fusion welding. In recent times FSW is being used for armor grade AA7075 aluminum alloy in defense, aerospace and marine applications where it has to serve in non uniform loading and corrosive environments. Even though friction stir welds of AA7075 alloy possess better mechanical properties but suffer from poor corrosion resistance. The present work involves use of retrogression and reaging (RRA) post weld heat treatment to improve the corrosion resistance of welded joints of aluminum alloys. An attempt also has been made to change the chemical composition of the weld nugget by adding B_4C nano particles with the aid of the FSW on a specially prepared base metal plate in butt position. The effects of peak aged condition (T6), RRA and addition of B_4C nano particles on microstructure, hardness and pitting corrosion of nugget zone of the friction stir welds of AA7075 alloy have been studied. Even though RRA improved the pitting corrosion resistance, its hardness was slightly lost. Significant improvement in pitting corrosion resistance was achieved with addition of boron carbide powder and post weld heat treatment of RRA.

Keywords: FSW; AA7075; Post weld heat treatment; Pitting corrosion

1. Introduction

High strength aluminum alloys are utilized extensively in the defense, aerospace, automotive and structural applications. AA7075 alloy is a high strength aluminum alloy of the 7000 series family based on Al–Zn–Mg system, in which Mg combines with Zn, and forms the strengthening precipitates, such as $MgZn_2$ and Mg_3Zn, contribute to the improvement in mechanical properties. Their strength is derived from the precipitation of η' phase (semi-coherent $MgZn_2$) in the grain interiors and of η phase (non-coherent $MgZn_2$) along the grain boundaries [1,2]. The attributes such as high durability, low density, superior cryogenic properties and response to age hardening made these alloys as a safe choice for fabricating armor plates, transportable bridges, girders, vehicles for military and railway transport systems, storage tanks, naval and marine applications. The fusion welding of AA7075 alloys is unattractive as the weld nugget shows poor microstructural and mechanical properties due to the presence of brittle dendritic structure, porosity, distortion and residual stresses, alloy segregation, hot cracking and hydrogen entrapment. Friction stir welding (FSW) is an autogenous solid state welding

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Peer review under responsibility of China Ordnance Society.

http://dx.doi.org/10.1016/j.dt.2015.01.002

technique where the joints are produced in solid state. The problem with fusion welded joints is overcome by using the FSW as there is no melting and recasting of the base material. Even though the joints of FSW show better mechanical properties than the fusion welded joints, the nugget zone (NZ) suffers from softening and poor corrosion resistance. Abnormal grain growth and thermal cycles, wide precipitate-free zones (PFZs) and coarse precipitates are the causes for poor corrosion resistance of NZ. The dissolution of grain boundary phases along the grain boundaries in the weld nugget zone where the Cu–Zn rich precipitates exists also contributes to corrosion in NZ. The onion ring bands that are created during FSW cause microstructural discontinuities in NZ leading to corrosion.

The literature review [3–10] revealed that the post weld heat treatments (PWHT) have been in use for improving the mechanical properties and corrosion resistance of NZ of friction stir welded (FSWed) joint in the high strength aluminum alloys. As-welded joints of 7xxx series aluminum alloys were treated in peak-aged condition (T6) for improving the strength and hardness but suffer from poor corrosion resistance due to precipitate free zones (PFZs) at the grain boundaries. Retrogression and reaging (RRA) is a specially developed heat treatment and has been studied by many authors for improving the corrosion resistance of FSWed AA7075 alloys [11,12]. With RRA treatment, corrosion resistance is improved due to reduced dislocation density in the nugget, increased grain boundary precipitate size, spacing and the presence of high volume fraction of η' with small amounts of η precipitates [13]. The dissolution of GP zones during retrogression and the segregation of η' phase during subsequent re-aging reduce the hardness, but the rupture toughness is improved [14–16]. The η' particles are responsible for the strength of the alloy while the η precipitates located at grain boundaries are responsible for the corrosion resistance of alloy. The corrosion resistance of the alloy improves with the increase in volume fraction of grain boundary precipitates. Dissolution of grain boundary precipitates during retrogression and re-precipitation in the matrix during re-aging improve the corrosion resistance. RRA of FSWed AA7075 alloy shown improved corrosion resistance, but with the expense of the joint strength [17]. As the 7xxx series aluminum alloy products are used in the harsh environments like military, marine and aerospace, further improvement of corrosion resistance and strength of the joints is needed. The mechanical properties and corrosion resistance of the aluminum alloy were improved by changing the chemical composition of the weld nugget. This can be achieved by the introduction of nano sized ceramic particles with the aid of FSW process. The literature on this research area of FSW is limited. Many authors reported that post weld heat treatments like peak aging (T6), retrogression and reaging (RRA) improve weld properties with modification of size, shape and distribution of secondary strengthening particles [18]. The present study is significant as the studies related to microstructure and pitting corrosion of armor grade AA7075 aluminum alloy friction stir weld nugget zone effected by post weld heat treatment and addition of boron carbide have not been reported so far. In view of the above facts, the present work has been aimed to improve the pitting corrosion resistance and mechanical properties of the friction stir welds of AA7075 alloy by using post weld heat treatments viz. T6, RRA and addition of boron carbide (B_4C) nano particles. B_4C was chosen for reinforcement due to its density (2.52 g/cm^3) and elastic modulus of (427 GPa).

Table 1
Chemical composition of AA7075 Alloy.

Material	Zn	Mg	Cu	Fe	Si	Ti	Mn	Cr	Al	Other, each
AA7075	5.1	2.5	1.2	0.5	0.4	0.2	0.3	0.2	91	0.05

2. Experimental details

30 μm-sized B_4C powder was ball-milled in a high energy planetary ball mill in wet mode using toluene as a liquid medium for 15 h. After the ball milling, the particle size was measured with XRD and was found to be 60 nm.The material used in this study was AA7075 alloy rolled plates with 8 mm thickness. Chemical composition of the base metal is given in Table 1. The dimensions of the plates were 240 mm × 150 mm × 8 mm. The top surface of the plate was drilled with 1 mm diameter drill at a distance of 2 mm in a zigzag form, as shown in Fig. 1. The holes are drilled along the length of the tool travel on the plates. The depth of the holes was 4 mm. The 60 nm-sized B_4C powder was filled in the drilled holes made on the plates. Initially the powder-filled holes of the plates were closed with the help of friction stir processing (FSP) tool. After processing with FSP tool, the processed region was then friction stirred with FSW tool. The FSP and FSW tools used for making the joint with the nano powder are shown in Fig. 1. The schematic representation of plates with holes for FSW is shown in Fig. 1. The optimum process parameters used for FSW are given in Table 2. Friction stir welding of same alloy was performed under the same welding conditions without the addition of the B_4C particles for comparative study. The samples were extracted from the welded plates for metallography, hardness measurement, and

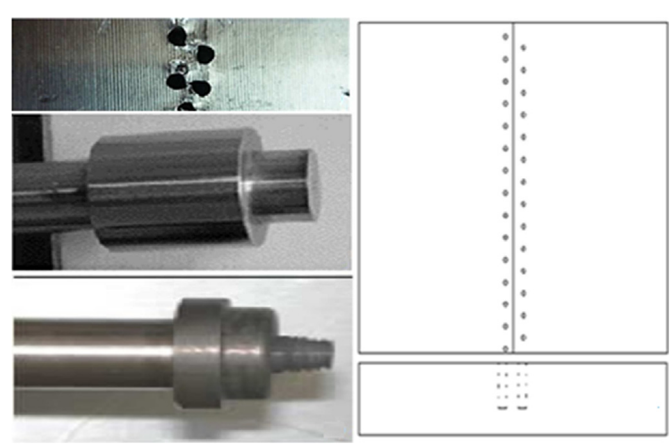

Fig. 1. Preparation of plates and tools used for FSW.