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Friction welding of tungsten heavy alloy with aluminium alloy

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ABSTRACT

This paper is a study of mechanical properties and microstructure of friction welded coupe of weight heavy alloy (WHA) with aluminium alloy (AA). Scanning electron microscopy (SEM) was used for investigation of the fracture morphology and phase transformations taking place during friction welding process. Chemical compositions of the interfaces of the welded joints were determined by using energy dispersive spectroscopy (EDS). Effects of friction time (FT) and friction pressure (FP) on the ultimate tensile strength (UTS) were studied by plotting graphs. The maximum average strength of 234 MPa, which is 84.78% of the aluminium alloy base material, is achieved at a friction time of 3.5 s and friction pressure of 40 MPa, respectively. The UTS of joints increases with increasing of FP and FT and then decreases after reaching the maximum value, with increase of friction load and time. Microstructure of friction welds consisted of fine equiaxed grains (formed due to dynamic recrystallization) and coarse grains in the periphery region on AA side. A plastic deformation in the direction of burrs is visible mainly on AA side. EDS-SEM scan line analyses across the interface have not confirmed the diffusion of tungsten and nickel to AA side. The nature of the friction welding joints is rather adhesive than diffusive. The EDS point spectrometry showed some enrichment of Ni-Fe matrix with Al atoms close to the joint. Absence of intermetallic phases was found in the weld interface on SEM level observation. The fracture procedes mainly through the cleavage planes at the interface.

1. Introduction

Tungsten heavy alloys (THAs) possess a characteristic microstructure consisting of spherical tungsten grains embedded in the matrix being usually Ni based solid solution containing tungsten, iron, cobalt and also other elements sometimes. These alloys are usually fabricated by liquid-phase sintering (LPS) in hydrogen atmosphere. THAs belong to the group of so called weight heavy alloys (WHAs).

WHAs have high density (16–18 g/cm^3), high ductility (10–30%), excellent strength (1000–1700 MPa) and offer good corrosion resistance. They also have a low coefficient of expansion and a high modulus of elasticity (German et al., 2009). Due to a unique combination of physical and mechanical properties, alloy is widely used in vibration dampers (Park et al., 2001), radiation shields (Sunwoo et al., 2006), mass balance for aerospace (Ryu and Hong, 2003), rocket nozzles in space crafts (Wang et al., 2005) and kinetic energy penetrators – KEP (Cai et al., 1995).

Recently, THAs have been specialised as kinetic energy penetrators, replacing conventional depleted uranium (DU) KEP, which is an extremely environmentally unsafe materials (Scapin, 2015). The penetrators are equipped with a soft aluminium alloy ballistic cup which protects the projectile against ricochet when it hits the armour plate, inclined usually at a very small angle with respect to projectile direction. Currently the ballistic cups are joined with main heavy alloy part of the projectile by a threat which is a time consuming and very expensive process. Thus natural is seeking more efficient method for joining the main part of projectile made from THAs with aluminium ballistic cup. One of such techniques is a rotary friction welding (FRW). However, there is a problem resulting from different physical and mechanical properties of the materials to be joined. Friction welding is a high efficiency welding technique applied for joining of similar materials. Furthermore, many friction welding joints, having various mechanical and metallurgical properties, such as: W with Cu, Al with Cu or stainless steel with pure Al, found practical application, as demonstrated

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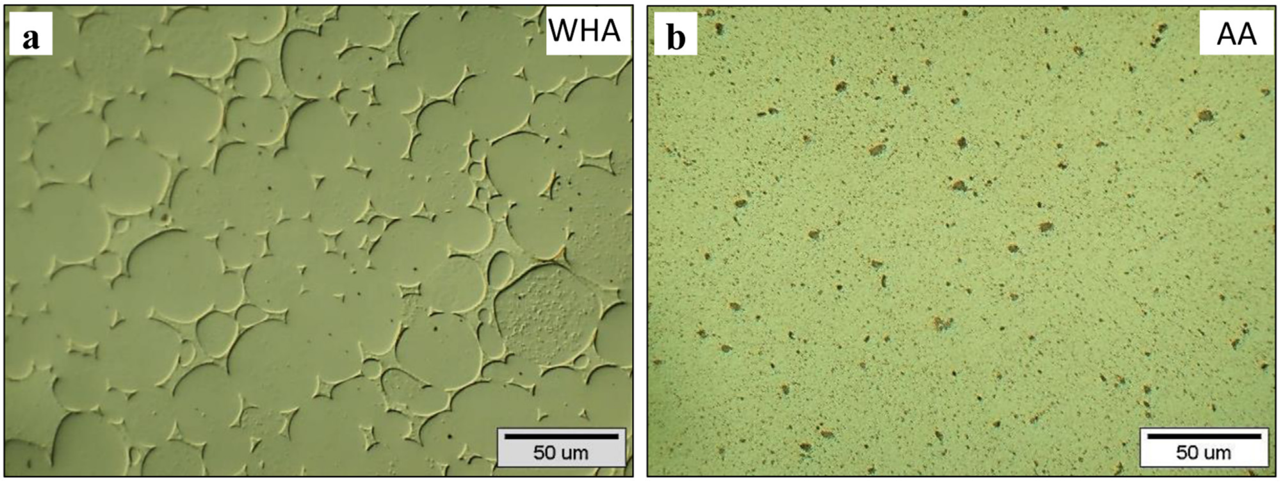

Fig. 1. Microstructures of base materials: (a) WHA and (b) AA.

by Aritoshi and Okita, (2003). Friction welding is also suitable for materials, which are welded with difficulty. Thus, in earlier works, dissimilar metals, such as stainless steel-titanium (Dey et al., 2009), aluminium-ceramic (Zimmerman et al., 2009), stainless steel-low alloy steel (Arivazhagan et al., 2011), maraging steel-low alloy steel (Reddy and Ramana, 2012), titanium-tungsten pseudoalloy (Ambroziak, 2010), aluminium-low carbon steel (Taban et al., 2010), niobum-tungsten alloy (Ambroziak et al., 2011), stainless steel-copper (Teker, 2013), ductile iron-stainless steel (Winiczenko and Kaczorowski, 2013), and ductile iron-low carbon steel (Winiczenko, 2016) were friction-welded by various researchers. Knowledge available from these works concentrated on structural and mechanical properties and metallurgical phase transformation.

The main goal of these investigations was to verify the possibility of friction welding method for tungsten heavy alloy joining. In addition, there is not report in the literature on the application of a solid-state technique for joining of tungsten alloy with aluminium alloy bars. Moreover, we would like to take a closer look at metallurgical phenomena, accompanying the friction welding of these alloys. As such, an EDS line, points and the map spectrometry techniques were used additionally.

2. Experimental procedure

2.1. Materials selection

A commercially available AA5454 type of non-heat treatable wrought aluminium alloy and conventional W-Ni-Fe type WHA, with typical 7:3 nickel to iron ratio, were used in experiments. They were machined to a bar of 20 mm in diameter and 100 mm in length. WHA was prepared by mixing an appropriate amount of powders, compacting and then liquid phase sintering (LPS) method. Details of WHA manufacturing are given by Das et al. (2010). Because of powder metallurgy method used for WHA preparation, its microstructure consists of 30–40 μm tungsten hard grains embedded in Ni-Fe matrix which, as sintered, is much softer, if compared to tungsten grains. The WHA specimens were ground and polished to get an even surface which was examined using an electron microscopy. The microstructures of base materials are shown in Fig. 1a and b. The tungsten grains are fairly rounded in the Ni-Fe matrix (Fig. 1a). There is also a microstructure visible, characterised by the direct welding between the tungsten grains. Additionally, the welding phase appears to be uniformly distributed. Porosity in the specimen is low and indicative of a successful sintering process, as reported by Das et al. (2011). The pores remaining in the specimen are mostly isolated in tungsten grains and clearly seen in the image. It can be seen in Fig. 1b that aluminium alloy contained a large number of undissolved second-phase intermetallic particles. The chemical compositions and mechanical properties of base materials were given in Tables 1 and 2, respectively.

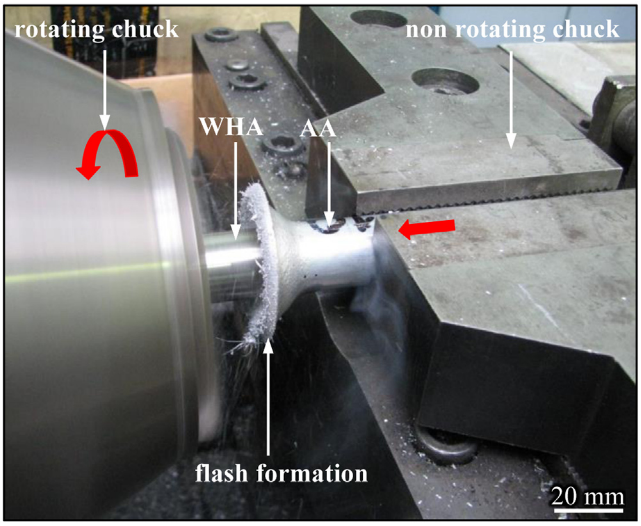

Fig. 2. Experimental setup for continuous drive friction welding.

2.2. Friction welding setup

The process of joining was carried out using a continuous drive friction welding machine (ZT4-13, ASPA, Poland) (Fig. 2). The surface for friction welding was prepared on the abrasive cut-off machine. The joined specimens had 20 mm diameter and 100 mm length.

As shown in Fig. 2, one workpiece is being rotated and the other is being held stationarily. When an appropriate rotational speed is reached, the workpieces are brought together under axial pressure. Abrasion at the weld interface heats the workpiece locally and axial shortening starts. Finally, the rotation of the workpiece stops and upset pressure is applied to consolidate the joint, as reviewed by American Welding Society (1989).

The friction pressure (FP) and friction time (FT) varied within the following ranges: FP = 40–80 MPa and FT = 0.5–9.5 s, respectively,