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Effect of friction pressure on the properties of friction welded MA956 iron-based superalloy

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Abstract

Effect of friction pressure on the properties of friction welded hot rolled MA956 iron-based superalloy plate, produced by mechanical alloying, has been investigated. Joining processes were carried out by various friction welding parameters. Tensile strengths and hardness values of the weld interface were determined and the microstructure features of these samples were investigated. Optimum friction pressure for this material was determined.

Keywords: Superalloys; MA956; Friction welding; Tensile strengths; Hardness

1. Introduction

Oxide dispersion strengthened (ODS) alloys, produced via mechanical-alloying (MA) technique, were mainly developed for gas turbine aerospace application [1]. ODS alloys have exceptional resistance to creep and oxidation at elevated temperature [2–4]. The high temperature strength of these alloys is due to the presence of fine, stable and uniformly distributed oxide particles which produce direct strengthening by acting as barrier to dislocation motion. In addition, their presence also results in directly in the growing of large elongated pancake-shaped grains with serrated grain boundaries during the secondary recrystallisation process. These coarse grains reduce grain boundary sliding at elevated temperature [1] and also slow down Herring–Naborro diffusional creep process.

Most of the powder metallurgy parts, such as ODS alloys, are produced near net-shape [5,6]. However, sometimes it might be necessary to joining these materials by either solid-state or fusion welding techniques. It was reported [7] that when using fusion welding techniques such as, gas tungsten arc welding, electron beam welding or laser welding; it is difficult to obtain high mechanical properties (especially creep strength) compared to those obtained on un-welded materials [8]. This was attributed to the agglomeration of the oxide dispersion in the weld zone together with the formation of fine grained, dispersion-free structure [9]. Thus solid-state welding is preferred for the joining of ODS superalloys [10].

Friction welding is a solid-state process in which the heat for welding is produced by direct conversion of mechanical energy to thermal energy at the interface of the samples without the application of electric energy or heat from the other sources to the samples [11,12]. Friction welding is made by holding a non-rotating sample in contact with a rotating sample under a constant or gradually increasing pressure until the interface reaches welding temperature and then stopping pressure rotating to complete the weld. The frictional heat developed at the interface rapidly raises the temperature of the samples, over a very short axial distance, to a value approaching, but below the melting range; welding occurs under the influence of a pressure that is applied while the heated zone is in the plastic temperature range [13–15].

The aim of this study was to join the iron-based superalloys MA956 without changing their elongated coarse grain structure with serrated grain boundaries. So friction

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welding, which is one of the solid-state technique was used with different welding parameters. In order to obtain similar microstructure and mechanical properties with unwelded materials, the optimum welding parameters were determined.

2. Materials and experimental techniques

Chemical composition of MA956 iron-based material employed is given in Table 1. This material was supplied in hot-rolled condition with 10 mm in thickness. Cylindrical test samples of 9 mm in diameter and 50 mm in length were prepared for friction welding. Samples were obtained from the longitudinal direction of the plate, parallel to the extrusion direction. Prior to friction welding the surface facing each other were machined by using a lathe.

Friction welding was carried out using a laboratory scale direct-drive friction welding device, which was designed and manufactured at Gazi University, Technical Education Faculty, Metallurgy Department. The welding parameters were as follows: friction pressure (P_1): 40–100 MPa, friction time (t_1): 6 s, forging pressure (P_2): 70 MPa, forging time (t_2): 5 s, rotation speed: 2880 rpm.

Welded samples were cut on the direction of cylindrical axes and then polished and etched in a solution of Glycia (40 ml HCl, 20 ml HNO_3, 30 ml glycerol). Optical examination was carried out on the etched samples in order to characterize the microstructure of friction welded parts by using Olympus microscope.

Tensile test specimens were prepared according to ASTM E 8M-00b. Ultimate tensile strength properties of the welded samples were determined. Hardness values ($VH_{0,2}$) were determined by using Zwick 3212/002 device. Starting from the welding interface with the interval of 0.30 mm four measurements were taken and a 5th one was taken from the base material. For tensile strength and hardness test studies at least three samples were examined for every parameter.

3. Results and discussion

3.1. Microstructure of base material

Hot rolled MA956 plate contained very irregular grains with convoluted grain boundaries (Fig. 1). However, the size distribution was very wide from a few micrometers to a few millimetres in length. Distributed fairly uniformly throughout the section, were a few, relatively coarse Ti(C,N) particles. In addition, some very fine stringers of rounded particles or pores occurred mainly in regions close to the outer surface. Even on very lightly etched samples, it was almost impossible to distinguish between particles and porosities on this fine scale (<1 μm).

Table 1
Chemical composition of MA956 hot rolled plate in wt%

Alloy	Fe	Cr	Al_2O_3	Ti	Y_2O_3
MA956	Bal.	20.51	3.77	0.13	0.41

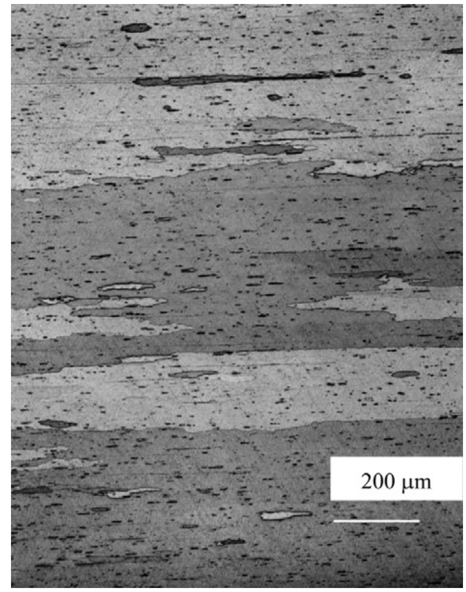

Fig. 1. As-received microstructure of MA956 hot rolled plate (a) $P_1 = 50$ MPa, $P_2 = 70$ MPa, $t_1 = 3$ san; (b) $P_1 = 50$ MPa, $P_2 = 70$ MPa, $t_1 = 8$ san; (c) $P_1 = 70$ MPa, $P_2 = 70$ MPa, $t_1 = 3$ san; (d) $P_1 = 70$ MPa, $P_2 = 70$ MPa, $t_1 = 8$ san.

3.2. Microstructures of welding zones

Grain orientations can be visible on both sides of weld interface of friction welded parts. This type of orientation is a typical characteristic of friction welding which is generally occurs in the rotational direction. In this study, elongated grains of MA956 were found to be oriented toward the sides from the welding interface. The intensity of orientation was found to be depending on the welding parameters.

During the welding of such ODS alloys, sparsely located dispersed oxide particles towards the weld metal from the heat affected zone (HAZ). In the case of elongated grains close to weld interface, grain orientation occurs from the interface towards the both sides as seen in Figs. 2(a) and (c), 3(a) and (c). However, in the case of small grains, orientation is reduced considerably. When orientated coarse grains, meet the small grains, orientation is again reduced as seen in (Fig. 3(d)). High friction pressure (Fig. 2(a) and (c)) resulted in high temperature in the weld area causing higher orientation intensity and wider weld area. It is clear that increasing friction pressure causes plastic deformation in wider area due to molten metal and consequently makes the orientation easier. However, applying forging pressure to this high molten area reduces the HAZ. Similar microstructures have been reported in some researches in which welding were applied to an iron-based superalloy was welded [8,16]. However, some others indicated that HAZ width and orientation intensity increased with friction pressure.