Journal of Manufacturing Processes 32 (2018) 151–159

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Evaluation of microstructure and mechanical properties of aluminum AA7022 produced by friction stir extrusion

Kamin Tahmasbi, Masoud Mahmoodi*

Department of Mechanical Engineering, Semnan University, Semnan, 3513119111, Iran

ARTICLE INFO

Article history:
Received 31 October 2017
Received in revised form 27 January 2018
Accepted 4 February 2018

Keywords:
Friction stir extrusion
Aluminum
Crystallite size
Dislocation density

ABSTRACT

Friction stir extrusion (FSE) is a process in which a sample is produced through the heat generated by the friction between die and materials, and the extrusion pressure. The extruded sample could be wire, tube, rod or another form. The wired samples were produced of aluminum alloy AA7022 at different rotational speeds and extrusion forces, and impacts of these two parameters were studied. The samples produced at higher rotational speeds and lower forces had a far better surface quality and less surface cracks were seen on them. The optical microscopy and scanning electron microscopy (SEM) were used to examine the microstructural properties of samples and the mechanical properties of specimens were studied by micro hardness and compression tests. Using X-ray diffraction technique and Rietveld method, the average crystallite size and micro-strain and dislocation density of samples were calculated and the yield strength of each sample was estimated by Taylor Equation. The average crystallite size and grain size were increased and the mechanical properties and dislocation density were decreased with the rise of rotational speed. Increasing the extrusion force to a certain level caused increase in yield strength of material. The experimental yield strength of compression test and Taylor's yield strength were compared with each other and had a good conformity.

1. Introduction

During last decade, severe plastic deformation (SPD) has been introduced as an effective method in production of the metal with an ultra-fine-grained structure. A wide range of investigations has been conducted to develop the SPD method and improve mechanical and physical properties of the materials. The friction stir extrusion was firstly invented by Thomas et al. [1] at Welding Institute of Cambridge, UK. In this process, a severe plastic deformation is occurred in base metal and the final specimen is produced with refined microstructure and desirable mechanical properties. This procedure can be used for recycling of machining scraps, production of wired raw materials, strengthening of powder metallurgy products. In FSE, unlike other extruding methods, there is no need to preheat the metal ingots to perform the process; thus, there would be a significant saving in materials, energy and cost as compared to traditional recycling methods. This process has been noticed by many scholars in recent years; however, it has been less investigated, compared to other SPD methods, because of novelty of the process.

Some researchers produced different wires via friction stir extrusion, and by studying on the process parameters and properties of the samples tried to improve this process. The recycling and production of AA2050 and AA2195 aluminum wires through FSE method have been recently examined by Tang and Reynolds [2]. This experiment has investigated defects of wire and its relevance to parameters of the process. Baffari et al. [3] have also investigated the influence of process parameters and initial temper of the base material on the process variables and on the extrudates' mechanical properties. Material flow during the FSE process and texture of wires was examined by Li et al. [4]. In this research, they inserted the AA2195 aluminum into the AA6061 aluminum as a marker to determine the material flow. Likewise, Sharifzadeh et al. [5] began to research about the production of magnesium wire through FSE method and examined the microstructure and average grain size in various magnesium wires. They also investigated the wear and corrosion resistance of produced magnesium wire. Li et al. [6] at their newest research have calculated the longitudinal and In-plane strains, generated in the wire produced by FSE. Numerical analysis and process simulation in order to determine the material flow and

* Corresponding author.
E-mail address: mahmoodi@semnan.ac.ir (M. Mahmoodi).

https://doi.org/10.1016/j.jmapro.2018.02.008
1526-6125/

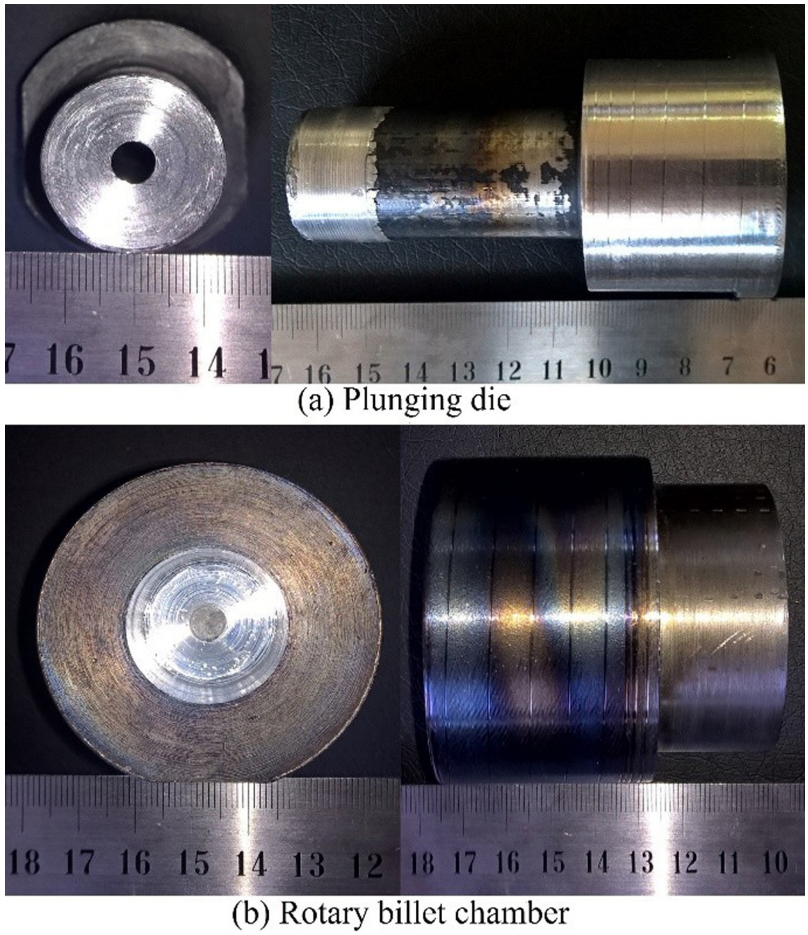

Fig. 1. Friction stir extrusion instruments (a) plunging die (b) rotary billet chamber.

temperature changes during the process is done, too. Zhang et al. [7] predicted the velocity field in FSE process, using analytical solution and CFD model and then validated experimentally. In their model, they assumed that there is no sliding contact between the die and materials and a model fluid without extrusion is considered. Zhang et al. [8] also simulated the heat transfer phenomenon and temperature field by using Fluent Software and measured temperature variations experimentally. Behnagh et al. [9] extruded magnesium wire via the FSE method and carried out a microstructural, thermal, and mechanical analysis through Eulerian-Lagrangian Finite Element Method (FEM).

Friction stir extrusion also is introduced as a new method for production of tubes and joining dissimilar materials. Abu-Farha [10] studied the production of AA6063-T52 aluminum tube via FSE method and examined the microstructure of produced tube in different areas. Dinaharan et al. [11] produced the pure copper tube via FSE method and examined its microstructural characteristics. Evans et al. [12] propounded the FSE as a new procedure, like friction stir welding, to joining dissimilar materials such as aluminum and steel. Sarkari and Movahedi [13] fabricated the aluminum tube through FSE process as well, and perused its microstructure and mechanical properties in different areas of the tube. Whalen et al. [14,15] investigated about the application of produced tube by FSE. They extruded tubes of magnesium alloys ZK60 and AZ91E from a cast billet and flake materials using the Shear Assisted Processing and Extrusion (ShAPE) machine. The extruded tubes exhibit desirable microstructure and crystallographic texture, which enhance their ductility and ability to absorb deformation energy compared to conventionally extruded tubes.

However, many aspects of this process have not been probed and it could be further improved. X-ray diffraction analysis can be used to determine the crystallite size, micro-strain, and dislocation density of materials. Dini et al. [16] proved that X-ray diffraction technique is an alternative technique to estimate the dislocation density. They calculated the average crystallite size, using the Rietveld method. According to previous researches can be found that the 7000 series aluminum alloy has not been studied by FSE process. In this paper, AA7022 aluminum wire is produced experimentally via friction stir extrusion. The AA7022 alloy is heat treatable wrought aluminum alloy and it is widely used in high-performance structural aerospace and transportation applications. By observing microscopic images and micro hardness and compression test results, the effect of rotational speed and extrusion force on the wire's microstructural and mechanical properties is studied and finally its properties are described using X-ray diffraction profile analysis and Rietveld method.

2. Experimental procedures

2.1. Friction stir extrusion process

In this research, the modified lathe is used to perform FSE process. The device's main components, a rotary billet chamber with an inner diameter of 24 mm and a plunging die with diameter of 23.7 mm, are shown in Fig. 1. The volume of the billet chamber where the chips are placed is 90.47 $cm^{3.}$ Both parts are made of H13 tool steel. The plunging die has a hole in the center. The central hole has a diameter of 5 mm, which is diameter of the produced wire