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Original Research Article

Experimental investigation of ultrasonic assisted equal channel angular pressing process

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ABSTRACT

Improvement of equal channel angular pressing (ECAP) efficiency is an important challenge for industrialization of this technique. The reduction of pressing load and improvement of material mechanical properties are among the most challengeable subjects during this process. In this research, commercial pure aluminum has been ECAPed at room temperature using conventional and ultrasonic vibration techniques to investigate the influence of ultrasonic wave on the pressing load and mechanical characteristics of deformed samples. The results showed that the superimposing ultrasonic vibration on the ECAP process not only decreases the required punch load, but also improves the mechanical properties of the material as compared to the conventional condition. Interestingly, the ultrasonic vibration assisted process leads to about 16%, 10% and 12% increments at the yield strength, ultimate tensile strength and hardness value respectively and also, 9% reduction at the punch load. Furthermore, the dislocation density of the sample produced by ultrasonic assisted ECAP is about 35% more than the achieved conventional sample.

1. Introduction

Fabrication of ultrafine grain (UFG) and nanostructure (NS) materials by equal channel angular pressing (ECAP) method is one of the most considered techniques of severe plastic deformation (SPD). This method results in the enhancement of mechanical, superplasticity and the other properties of materials [1–3]. During this process, a cylinder or square shape work-piece is pressed through a die with two identical cross-sectional channels intersecting at a die channel with the outer corner angles of Φ and Ψ, respectively. Since there is no change at the dimensions of the sample after pressing, this process can be repeated for a number of times to achieve the desired characteristics [4,5]. ECAP is considered to be a friction sensitive process and studies have shown that the increment of the friction factor increases strongly the forming force. Also, there exists a critical friction factor in which, the dead metal zone is formed during the process. Thus decreasing the sliding friction between the work-piece and the die especially for the higher passes in the entrance channel would help to reduce the pressing load as well as increase the efficiency of the process [6,7]. Hence, it has been proposed to reduce the forming load by

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simultaneous application of ultrasonic vibration (UV) during the process [8–10].

In recent years, the attention for application of ultrasonic energy on the various metal forming processes has been considerably increased. The investigation by researchers has shown beneficial effects such as lower forming load, lower number of steps in the process, better surface finish, material softening and acoustoplastic effect [8–12]. The experimental study by Izumi et al. on the effect of superimposed ultrasonic vibration during compression test showed that the compressive flow stress is decreased by applying UV. In addition, the UV efficiency is related to the metal properties such as acoustic impedance, Young's modulus, melting point, work hardening and stacking fault energy [13]. Reduction in the both flow stress and forming force in the hot upsetting process via axial ultrasonic vibration technique has been reported by Hung et al. [14,15]. Also, the influence of UV on processes like hot upsetting cannot be justified only by the simple mechanism like frictional effect at the interface. In fact, it can be related to the ultrasonic energy absorption by the dislocations. Experimental and numerical investigations by Liu et al. revealed that upsetting method with ultrasonic vibration leads to fabrication of ultrafine grain structure at the pure copper cone tips [16,17]. The application of ultrasonic vibration on the cold forging process indicated that the service time of trimming knives is improved by about 100% at the cold rolling process due to the tool steel mechanical properties enhancement [18]. The study by Bunget and Ngaile confirmed that the extrusion process of difficult-to-lubricate materials can be carried out using UV. The results showed significant reduction at the extruded force and better surface property of final sample is achieved [19]. Investigation by Mousavi et al. on the ultrasonic vibration assisted extrusion process indicated that the magnitudes of forming load and flow stress are reduced significantly [20]. Jimma et al. explored the influence of ultrasonic vibration on the deep drawing process. The blank holder and the die were radially vibrated which led to the increment at the drawing ratio, better sheet deformation and protection against cracks and wrinkles [21]. The influence of ultrasonic waves on the strip drawing process studied by Siegert and Ulmer showed that the friction value is reduced and the surface quality of the samples are improved [22]. The studies by Hayashi et al. and Murakawa et al. demonstrated that improved drawing resistance, enhanced lubrication condition and wire breakage reduction can be obtained by imposing UV to the wire drawing process. Furthermore, the radial ultrasonic vibration is more effective than the axial one on the increment of critical rate by about 10 times [23,24]. Ashida and Aoyama surveyed experimentally and numerically the press forming process behavior via ultrasonic vibration and showed that this technique leads to the lower forming load, higher formability and lower crack formation as compared to the conventional one [25]. It can be concluded that diminution of the forming load, decrease of material flow stress, reduction of friction between the interface of the sample and the die, better surface quality of the processed sample, higher dimensional accuracy of the produced sample, rise at the material temperature during the process and the spring-back reduction in the sheet forming are the most advantages of ultrasonic vibration application in the metal forming processes.

Despite the significant merits of ultrasonic vibration application on the various metal forming processes, this technology has not been developed for severe plastic deformation methods, hence there is a little study in this field [8]. The equal channel angular pressing method equipped with ultrasonic vibration technique was investigated by Djavanroodi et al. and they verified that lower pressing force is required by using ultrasonic vibration. Also, the influence of vibration amplitude is more sizeable than frequency on the required force reduction [9]. Ahmadi and Farzin [10] investigated numerically the effect of superimposing ultrasonic vibration on the punch during the ECAP process. They showed that there is a reduction in the forming force and this force reduction depends on the vibration amplitude and the die velocity. Application of ultrasonic vibration on the tubular channel angular pressing studied by Faraji et al. indicated that the radial ultrasonic is the dominant factor as compared to the axial one on both the strain behavior and the pressing force [26]. Also, the results showed that vibration of the die is more significant than either mandrel or punch.

The authors have made a detailed finite element investigation on the effect of ultrasonic vibration during ECAP process [9]. In continuation of their previous studies, the purpose of this research is to investigate experimentally the influence of ultrasonic vibration application on the equal channel angular pressing process. Hence, the ECAP process has been experimentally equipped with ultrasonic vibration technique and its effects have been evaluated on forming load and mechanical properties of deformed billet.

2. Experimental procedure

Cylindrical shape commercial pure (CP) aluminum (Al1070) with the chemical composition listed in Table 1 was prepared with the length and diameter of 150 mm and 20 mm, respectively. To make sure that there is no non-homogeneity in the structure, all samples were annealed at 380 °C for half-an-hour before the ECAP process. ECAP die with the die channel angle of 90°, outer corner angle of 15°, channel diameter of 20 mm, the entrance and exit channels length of 200 mm and 230 mm was designed and manufactured as shown in Fig. 1. To perform the ECAP process, a hydraulic press with the capacity of 400 tons and ram speed of 2 mm/s were

Table 1 – The chemical composition of commercial pure aluminum used for this study.

Element	Al	Fe	Sn	Mg	V	Zn	Ti
Weight percent	99.737	0.127	0.043	0.030	0.012	0.009	0.002