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Effect of equal channel angular pressing on fracture toughness of Al-7075

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ABSTRACT

In this paper, influence of equal channel angular pressing (ECAP) on the fracture behavior of Al-7075 alloy is experimentally investigated. The specimens are successfully processed by ECAP methodology up to four passes using different routes. Transmission electron microscope (TEM) images showed that after four passes of ECAP, the average grain size is refined from 40 μm to less than about 500 nm. The percentage increase in yield strength, ultimate strength and microhardness of the specimens after four ECAP passes was 230, 90 and 110 respectively. Standard tests on the disk-shaped compact DC(T) specimens showed that fracture toughness is decreased up to 8% at the first ECAP pass while after four passes, this parameter roused to 17% higher than that of annealed condition. Furthermore, scanning electron microscope (SEM) micrographs demonstrated that ductile fracture mechanism with large dimples occurred in the annealed samples, changed to limited ductile fracture with fine dimples after ECAP process. This research provides new insights into the effect of ECAP and grain refinement on the fracture behavior of materials.

1. Introduction

It is well-known that ultrafine grained (UFG) microstructure can considerably improve some mechanical properties of materials such as strength and hardness [1–13]. Equal channel angular pressing (ECAP), developed by Segal [14], is one of the most common techniques used by researchers to fabricate UFG materials based on severe plastic deformation (SPD). In this method, the specimen is pressed into a die comprised of two intersecting channels with same cross-sections [15]. It is shown that parameters such as the die channel angle and the channel length have considerable effect on the magnitude of plastic strain of deformed samples [16]. Among the four common routes A, C, B_A and B_C for performing ECAP process, two routes A and B_C have been more frequently used [17,18]. Contrary to the route A in which the samples are pressed in consecutive passes without any rotation, the specimens are rotated by 90° in the same direction at each pass of route B_C [19,20]. One of the promising advantages of this method is its capability to produce a bulk of UFG materials which makes it possible for ECAP to be scaled up and industrialized. For instance, ECAP has been successfully commercialized for the production of sputtering targets in the electronic industry at Honeywell [21]. The critical aspects of industrialization of ECAP which have to be taken into considerationare also discussed in [21]. Moreover, advanced fabrication technologies of UFG Ti and shape memory Ni–Ti alloy with superior mechanical properties and enhanced biocompatibility for medical implants are given in [22].

Over the last few decades, numerous numerical and experimental researches have been conducted to evaluate the relation between microstructural and mechanical properties of the nanostructure materials. Number of properties such as strength,

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ductility, microhardness, dislocation structure and homogeneity of some nanostructured materials such as aluminum alloys [2–7], Cu [1,8], Ti [9,10] and low carbon steel [11–13] has been studied in detail. For example, Zhao et al. [23] showed that the ultimate tensile strength and the hardness of commercially pure titanium (grade 1) increased from 485 MPa and 175 Hv to 765 MPa and 231 Hv respectively while the elongation decreased from 64% to 48% after four passes of ECAP process. In a similar work, Soliman et al. [18] studied the effects of ECAP on mechanical and microstructural properties of Al-1050 alloy and reported similar results. Additionally, it is demonstrated that ECAP technique enhances not only the mentioned properties, but also some other characters of materials such as fatigue endurance limit, corrosion resistance and impact toughness [24–26]. However, due to high incidence of cracking and segmentation, processing of some materials like Ti by ECAP is very difficult at room temperature [23,27]. Recently, a novel technique is presented by Djavanroodi et al. [28] for processing such materials by ECAP. In this technique, samples are covered with thin walled tube made of ductile materials in order to generate a smoother strain distribution on cross-section of samples [28].

Spurred by low density and high strength and toughness, heat treatable Al-7075 alloy has been considered as one of the main materials for the automobile, aerospace and construction applications [29,30]. For making this alloy more applicable, a combination of grain refinement and precipitation hardening can be used to achieve superior strengthening [29–32]. This fact has been the aim of some works over the last decade. For example, the effect of pre-ECAP aging, post-ECAP aging and dynamic aging during ECAP on microhardness and strength of Al-7075 was studied by Shaeri et al. [29]. It was shown that higher mechanical properties can be attained by dynamic aging during ECAP process [29]. Similar results have been reported for Al-6082 alloy by Vaseghi et al. [33]. Moreover, performing ECAP on 7xxx-series aluminum alloys may also affect the microstructure in a different way. For example, imposition of the high pressure during the pressing process may cause the breaking and fragmentation of precipitates [15]. It has been observed from photomicrographs of Al-7034 alloy that the large precipitates have been broken after ECAP [15]. Furthermore, depending on the composition of the alloy, applied pressure and temperature, ECAP may change the precipitate orientations and cause precipitate dissolution, precipitate formation and coarsening [15,34]. It has been reported in [34] that the high density of mobile dislocations in ECAP-processed Al-7136 increases the dissolution of small precipitates and the formation of large ones by coalescence. On the other hand, the effect of ECAP on the mechanical properties of annealed Al-7075 has been also investigated [7,35]. Kumar et al. [35] showed that after the ECAP process the tensile yield strength, ultimate tensile strength and microhardness of annealed Al-7075 alloy increased by 168, 73 and 93%, respectively. They also concluded that using route B_C will result in samples with higher strength in comparison with other routes [35].

Nanostructured materials may not be used in engineering structures and instruments unless a detailed understanding of their fracture properties is provided. There are some works in the literature that are focused only on fatigue crack growth behavior of UFG materials [36–41]. For example, it is shown that despite the fatigue endurance limit, fatigue crack growth threshold ΔK_{th} is

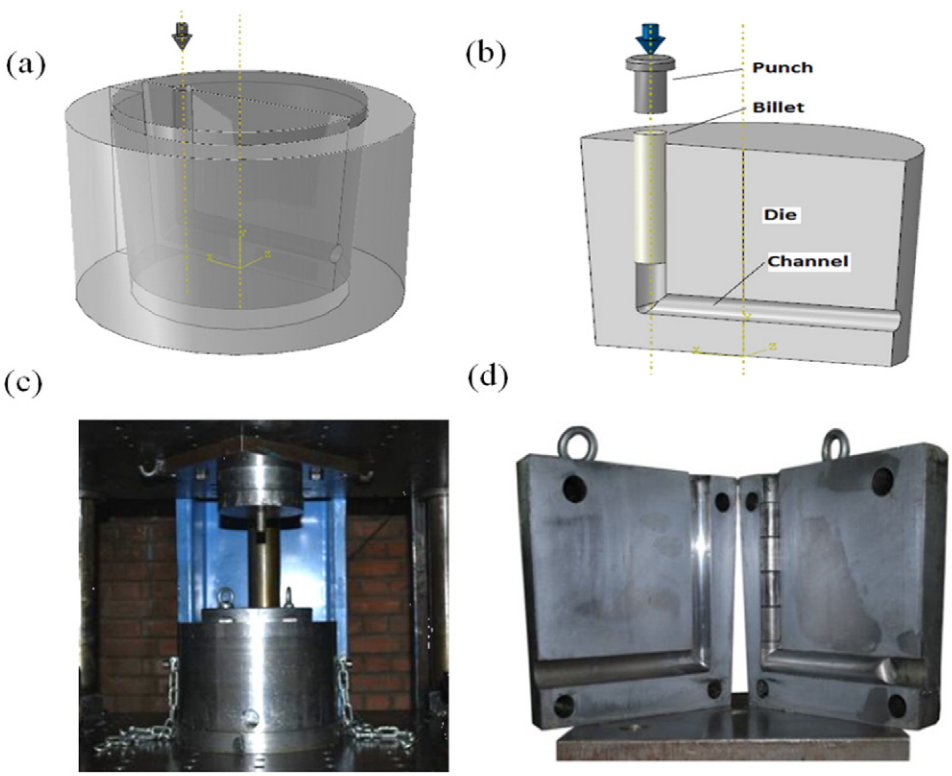

Fig. 1. (a) 3D view of the ECAP die, (b) cross-section of the die, (c) die ready for ECAP and pressing and (d) ECAP-processed sample inside the die [7].