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Continuous ECAP process design for manufacturing a microstructure-refined bolt

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ABSTRACT

In this paper, split dies combined with a spring-loaded auto-fastening system are newly proposed to continuously apply an equal channel angular pressing (ECAP) process to a multi-pass bolt forming process. The proposed spring-loaded ECAP set-up was used to produce microstructure-refined materials in a continuous manner. Experiments for a single pass of the ECAP followed by four stages of the bolt forming process were carried out to manufacture a microstructure-refined bolt made of an aluminum alloy 6061 by using the multi-stage former at room temperature. The present study clearly showed that manufacturing the microstructure-refined bolt is possible with the proposed die set-up with a conventional material. The proposed process design might be beneficial in using the ECAP as part of a continuous process sequence to increase the mechanical strength of the material without adding more alloying elements in industry.

1. Introduction

Severe plastic deformation (SPD) processing by an equal channel angular pressing (ECAP) has attracted a noticeable attention because it is an effective technique to physically produce bulk nanostructured materials with enhanced mechanical properties [1,2]. As this forming technique greatly refines the grain size by accumulating plastic strain into the workpiece without changing its cross-sectional shape, the ultrafine-grained materials show high strength and toughness [3–6]. Nevertheless, the ECAP technique in its original principle design, which might be the design of the conventional solid die and split dies, has critical disadvantages such as limitation of the workpiece length and the limited travel distance of the press ram [7,8]. This means that the existing ECAP process is a discontinuous process resulting in low production efficiency and high cost.

Several schemes have been proposed for making a continuous SPD method to overcome such disadvantages (for production of the ultrafine-grained materials). A continuous constrained strip shearing (C2S2) process [9] and conshearing process [10] were introduced for processing thin aluminum strip by employing the friction between rollers. An ECAP-Conform process for alternative approach is proposed based on the Conform process for continuous extrusion of metal wires [8,11,12]. A pioneering study showed that these procedures were capable of producing grain refinement in aluminum and titanium alloys. However, these processes use the frictional force to push the workpiece through a shear deformation zone of a modified ECAP die and may have difficulty to process relatively large bulk materials with high strength.

For practical application of the ultrafine-grained materials processed by the warm ECAP process, Zhernakov et al. [13] manufactured titanium bolts with tensile strength and fatigue endurance enhanced. Yanagida et al. [14] checked formability of steels subjected to the cold ECAP process and manufactured a micro bolt using the ultra-fine grained material. Choi et al. [15] proposed the bolt forming process using the ultrafine-grained aluminum alloy processed by an ECAP process accounting for the change of formability of the material depending on the processing routes. However, their work is limited on a laboratory scale and applications of the process are probably effective in manufacturing expensive products where the production cost is not a major concern.

In the present study, split dies combined with the principle of a spring-loaded system, which is useful for cold heading, are newly proposed to solve discontinuous characteristics of the ECAP process. Experiments for a single pass of the ECAP as an intermediate forming operation will be carried out to process the aluminum alloy 6061 by using a multi-stage former, which is commonly used in a factory production, at room temperature. Subsequent bolt forming based on the extrusion process is carried out to investigate the effects of the ECAP process on improvement of mechanical properties and microstructure change of the final product.

Two multi-stage manufacturing processes were designed in order to develop a high strength aluminum alloy bolt using the

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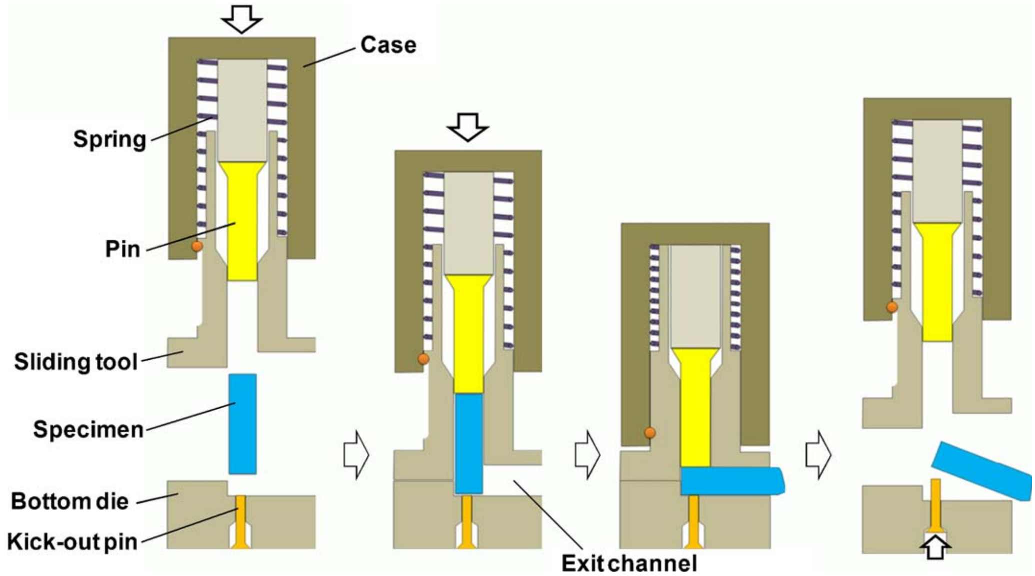

Fig. 1. Schematic illustration of operating scheme for a spring-loaded ECAP set-up.

conventional and newly proposed bolt forming processes. In the newly proposed bolt forming process, ECAPed specimens were used to manufacture bolts with standard metric thread M8 by following the same sequence of the conventional bolt forming process which is common for manufacturing ordinary bolts at practice.

Finally, tension tests were applied to investigate strength increase in the developed bolts. Vickers microhardness tests were also carried out to examine the distribution of local strength at three different regions of the head, neck and body in the bolts manufactured. In addition, microstructure changes in the specimens were investigated using transmission electron microscopy (TEM) in order to understand the effect of shear deformation on strength increase in the developed bolt formed by the newly proposed process. Finally, fatigue strength was investigated in the present work.

2. Experimental procedures

The experiments were conducted using the commercial aluminum alloy 6061 with a chemical composition, in wt.%, of 0.97% Mg, 0.63% Si, 0.20% Fe, 0.24% Cu, 0.15% Cr, 0.03% Mn, 0.01% Ti, 0.003% Zn and balance Al. The specimen was prepared by T6 treatment which consists of solid solution treatment at 530 °C for 3 h and artificial aging at 175 °C for 8 h.

Processing by the newly proposed spring-loaded ECAP die system was conducted at room temperature using the schematic shown in Fig. 1. The principle of processing is as follows. Feeding of the specimen takes place during sliding tool withdrawal when the top die moves up and there is no contact. The sliding tool with the input channel and bottom die forms the output channel when the case moves towards the bottom die. This contact results in dies consisting of the die channel angle of 90° and die corner angle of 20°. The upper pin pushes the specimen to the shear deformation zone of the channel and simple shear deformation occurs. The coil spring suppresses separation between the sliding tool and the bottom die, thus the ECAPed specimen is formed without flash. After the extrusion is complete, the sliding tool retreats and the deformed specimen will be kicked out from the experimental set-up by the lower pin. In this way the specimen is deformed in the same manner during a cyclic contact and processing.

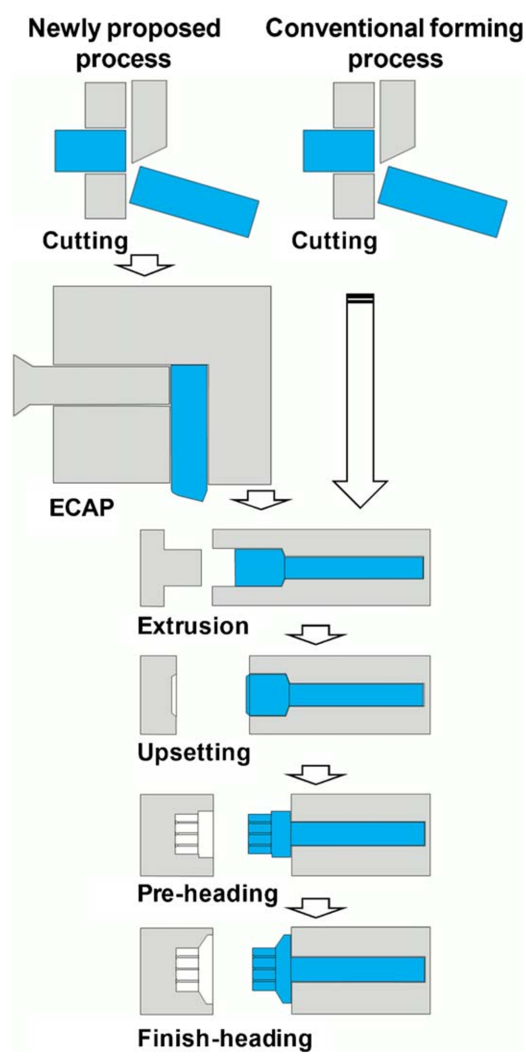

Fig. 2. Schematic illustration of bolt forming sequences for the newly proposed and conventional bolt forming processes.