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Large-scale manufacturing of aluminum alloy plate extruded from subsize billet by new porthole-equal channel angular processing technique

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Abstract: To manufacture plate by the combination of equal channel angular processing (ECAP) and porthole die extrusion techniques, a novel technique, namely portholes-equal channel angular processing (P-ECAP), was studied. Extrusion of AL6005A plate used for the bullet train plate was investigated by finite element method. The relevant porthole dies involving ECAP technique in channels were designed. Dimensional changes in the scrap part of the extrudate obtained after extrusion from the P-ECAP die, with different channel angles, were predicted. Effects of the channel angle and extrusion speed on the maximum temperature of the workpiece and other field variables were evaluated. At the channel angle of 160° of P-ECAP dies, the extrudate exhibited the optimal performance and the least amount of extrudate scrap was obtained. The optimal extrusion speed was 3−5 mm/s. Moreover, with the increase in ram speed from 1 to 9 mm/s, the peak extrusion load increased by about 49% and the maximum temperature was increased by about 70 °C. The effective strain exhibited ascending trend in the corner of the ECAP deformation zone. In the solder seam and the side of die bearing of extrudate, the maximum principal stresses were tensile stress.

Key words: subsize billet; porthole die; equal channel angular processing (ECAP); extrusion

1 Introduction

Rolling is a traditional large-scale plate production technique; however, there are a number of steps involved in the process of rolling to manufacture plate [1,2]. Moreover, there are certain inefficiencies and disadvantages of rolling process. In contrast, the aluminum (Al) alloys plate can be manufactured in one step by extrusion technique. Recently, extensive research efforts have been devoted to develop novel extrusion methods because of the significant increase in the use of Al extrusions for wide range of applications. The one-shot die pressing is a new process to produce Al alloys extrusion plate on large scale with high material utilization, less number of steps, and high efficiency, leading to the production of high quality products. This is due to the triaxial compression stress state of the workpiece. In contrast, the rolling process involves biaxial compression stress state.

It is well-known that Al alloy is extremely difficult to extrude, in particular, when wide range of extrudate cross-section shapes is obtained and the ratio of flakiness on shape of the extrudate is very large [3]. The extrusion load required in traditional processing is extremely high. Extrusion load of expanding extrusion is smaller than that in the traditional processing because of small extrusion ratio. However, there is some gross imperfection on the edge of expanding extrusion product. For Al alloy, the optimization of the extrusion process and die structure for obtaining a reasonable extrusion speed without affecting extrudate surface and microstructural quality is extremely complex. For some special solid profiles with large spread, the technique may need the plane diffluent and expanding extrusion technology to save energy, which increases design difficulties. Therefore, combination of significantly effective techniques is highly desirable because of the above mentioned complicated influencing factors. In practice, traditional "try-and-error" method is always

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used for die design and process optimization, which is costly and results in the wastage of production time or extension of research and development cycle. Therefore, process simulation technology based on finite element method (FEM) is a viable alternative predictive tool for preliminary engineering in this new research area.

Equal channel angular pressing (ECAP) is attracting significant attention in several severe plastic deformation (SPD) [4] processing methods which are now available. In this method, the sample in the form of a relatively short rod is pressed through a die constrained within a channel bent through an angle [5,6]. The ECAP process developed by SEGAL [7,8] is an ingenious method of SPD which can be applied to numerous materials with enormous advantages over the other methods of deformation. According to Refs. [9−15], ECAP process has been successfully used to produce nanostructure metal materials. For example, the yield stress after six pressings was 425 MPa in the post-ECAP aged 6061 Al alloy; however, it was 275 MPa in the ECAP 6061 alloy without a special heat treatment before and after ECAP [16].

Significant research efforts have been devoted to change and improve the ECAP die structure. LI et al [14] demonstrated that a shorter outlet channel led to a longer steady-state region and a lower working load, but there was a higher tendency of upward bending of the deformed workpiece. YOUNG et al [17] designed continuous ECAP process for manufacturing a microstructure- refined bolt, and showed that the manufacturing was possible using a proposed die set-up with a conventional material. Thus, the above mentioned literature studies have confirmed that the ECAP process is an effective approach for producing bulk fine grain structured materials [15]. However, in-depth research on the deformation homogeneity within the flat square cross-section of the samples obtained from porthole die involving ECAP process in channels to achieve continuous production has not been investigated.

Limited attention has been paid to the application of ECAP in porthole die. Compared with the proven technique of ECAP, the application of ECAP in porthole die is a novel research area. Few practical applications employ ECAP technique to obtain large ratio of length to width on shape of the extrudate, such as plate for bullet train. Importantly, conventional ECAP is a discontinuous process involving a repetitive sequence in which the workpiece is inserted into the die, pressed through the die, removed, and then reinserted to impose an even higher strain. This indicates that, although ECAP is an effective processing tool for laboratory research, it is labor-intensive and not easily adapted for use in large-scale manufacturing [12].

Porthole-ECAP (P-ECAP) die is a combination of the two techniques of ECAP and porthole die. YANG et al [13] designed a new die of P-ECAP. In this study, a pair of channels with an angle set up in two portholes of a die was employed. It avoided some of the disadvantages of ECAP, such as discontinuous process and not easy adaption for use in industrial operations. Moreover, there are two added benefits to the extrudate. First, the flow direction of alloy through each channel with an angle was the same as the ram direction. Second, there was an expanding impact on extrudate breadth size. The extrudate breadth size was greater than that of initial workpiece because of expanding impact of the channels angle. Based on the above mentioned analysis, a novel energy saving technique was introduced to manufacture plate for the bullet train. In this study, the new technique of P-ECAP and its process for manufacturing extrusion plate was introduced and investigated to improve the industrial applicability of ECAP in terms of its continuity and efficiency.

2 FEM model of P-ECAP extrusion

2.1 Design of P-ECAP dies with different channels angles

In this work, we firstly developed geometric models of the container, workpiece and other extrusion tooling based on SOLIDWORKS software. Figure 1 shows the dimensions and cross-section of the sheet-metal profile used in the present study. According to the P-ECAP die technique character and workpiece geometrical character of extrusion to manufacture the aluminium sheet-metal, one half of the geometric model of P-ECAP die is shown in Fig. 2. The sheet-metal is a general industrial profile with large flakiness ratio, thus presenting quite a challenge to the die designer and extrusion process

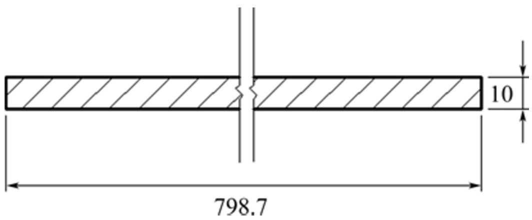

Fig. 1 Cross-sectional shape and dimensions of extrudate (unit: mm)

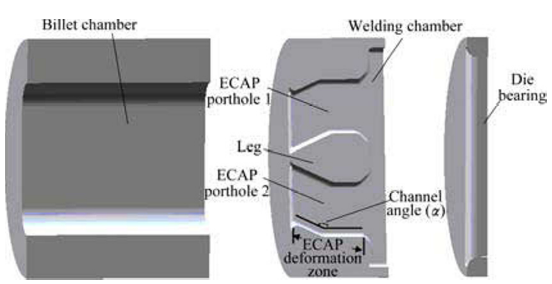

Fig. 2 Basic design of P-ECAP die (a half model)