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Equal channel angular pressing with converging billets—Experiment

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ABSTRACT

A new concept of equal channel angular pressing (ECAP) with converging billets is proposed and tested experimentally. In its basic configuration, the new ECAP process uses two equal square input channels converging into a single output channel, which is twice as wide as the input channels so that it can accept two converging billets. The contact surface between converging billets plays the same role as a movable die wall in the output channel of classical ECAP and thus reduces friction and the process force. The process productivity is doubled and material pickup, especially problematic in the output channel, avoided. This paper presents results of experimental trials of the new process using purposely designed tooling incorporated in a horizontal press with three hydraulic cylinders. One pass of ECAP with converging Al 1070 billets has been carried out and the resulting hardness distribution and microstructure examined. It is concluded that the new process is a feasible version of ECAP both in the engineering and the micro-structural terms, with the added benefit of doubled productivity as well as friction and force reduction.

1. Introduction

Bulk metals with ultrafine grained (UFG) structure, characterised by the average grain size $<1\ \mu m$, draw substantial attention due to their unique mechanical and physical properties such as improved strength described by the Hall–Petch relationship [1], enhanced superplastic forming [2], better biocompatibility [3] or particular suitability for microforming [4]. The preferable method of producing bulk UFG metals, which avoids the health hazards associated with nanopowders, is severe plastic deformation (SPD) [5]. In this method, a very large plastic deformation (true strain 3–10 depending on the metal) "subdivides" coarse metal grains into sub-micrometre size grains. Unlike traditional metal forming processes, SPD processes retain the shape of the workpiece.

Equal channel angular pressing (ECAP), originally proposed by Segal et al. under the name of equal channel angular extrusion [6], is the most popular SPD process used to produce UFG metals. In this process (Fig. 1), a square or cylindrical billet is pushed by a punch through an input constant profile channel to an output channel of the same profile orientated at an angle $\geq 90^\circ$ to the previous one. Plastic deformation of the material is caused by simple shear in a thin layer along the diagonal plane at the channel crossing. The process is usually repeated several times with the billet being rotated about its axis between consecutive passes. The process is simple in terms of tooling and machines used, however, it suffers from friction present in the die channels, which increases the process force and tool contact pressure, limits the length of billets processed and causes material pickup. Good illustration of this last problem is a die segment used in three-turn 3D-ECAP [7], which shows a layer of aluminium sticking to the bottom surface of die channel (Fig. 2). To reduce friction, a concept of movable die walls both in the input and the output channel of the die was proposed [8]. Less complicated seems to be a movable wall representing the bottom part of the output channel; it was realised in practice in industrial ECAP of large plates for sputtering targets [9]. But even in this case the introduction of a movable die wall leads to a more complex and expensive ECAP device. Even if friction between a billet and the bottom part of the output channel is eliminated, it does not disappear completely; it is just moved to a new location between the stationary and movable device elements. Thus friction reduction in the output channel still remains a challenge.

A new solution to the problem of friction in the output channel of an ECAP die has been proposed recently. It is based on the idea of ECAP with converging billets, which was explained and modelled using finite element (FE) simulation [10]. The current paper focuses on checking the engineering feasibility of this idea by carrying out a laboratory experiment and investigating changes in properties and microstructure of the processed billets.

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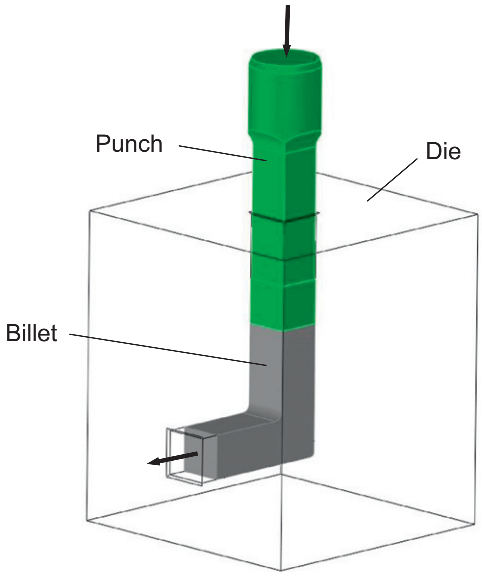

Fig. 1. Process configuration for classical ECAP.

Fig. 2. Material pickup on the bottom surface of a 3D-ECAP channel.

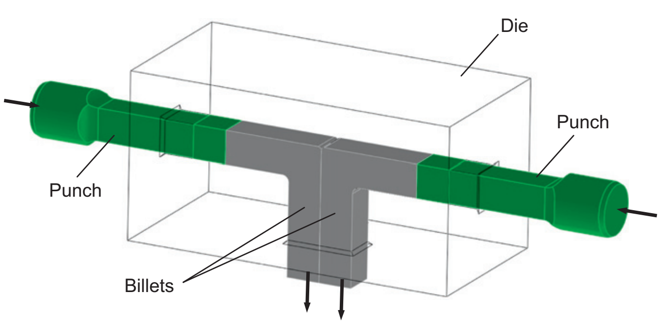

Fig. 3. Process configuration for ECAP with two converging billets.

2. Concept of ECAP with converging billets

In its basic configuration (Fig. 3), the new ECAP system uses two substantially equal square or rectangular input channels converging into a single output channel, which is twice as wide as the input channels so that it can accept two converging billets. The contact surface between converging billets plays the same role as a movable bottom wall in the output channel of classical ECAP discussed above. It reduces friction and the process force. This effect is achieved without using a complex die with movable parts. Instead, two punches are used to push two billets synchronously from the opposite sides. The system doubles productivity compared to the case of processing a single billet. Fig. 4 shows comparison of classical ECAP of a single billet (without moving die walls) and ECAP with two converging billets in terms of strain distribution [10]. Friction coefficient in both processes is the same and equal $\mu=0.1$. Strain appears to be similar, except the bottom part of the billet, where it is smaller for ECAP with converging billets. This is related to the fact that, in the absence of friction on the bottom part of the billet, the die corner at the channel intersection is filled less; the same effect would be observed in ECAP with a movable bottom wall. A remedy might be back pressure, which improves filling of the die and makes strain distribution more homogeneous [10]. ECAP with two converging billets reduces friction in the output channel, which leads to a lower value of the maximum process force [10]. For friction coefficient $\mu=0.1$, the force reduction predicted by plane strain FE simulation was 23% (Fig. 5).

3. Machine

The machine chosen for experimental trials (Fig. 6) was originally used at AGH University of Science and Technology, Krakow, Poland [11] for cyclic extrusion compression (CEC), which is another SPD process. The CEC machine was equipped with two hydraulic double action horizontal actuators opposing each other. Their work cycle involved fixing the die in the horizontal direction with external actuators and then using internal actuators to move the extrusion punch at a controlled speed while the compression punch provided only back pressure. Using the CEC machine for ECAP with converging billets also involved fixing the die in the horizontal direction but required a different type of punch control to allow the punches to move in the opposite directions and at the same speed. Another feature of the original CEC machine was a horizontally split die, whose halves were kept together during the process by a vertical hydraulic actuator. On process completion, the actuator lifted the upper half of the die to enable billet removal. In ECAP with converging billets, the billets could leave the die using a lateral hole opposite the vertical actuator so the die did not have to be split in the horizontal plane. Thus the clamping action of the vertical actuator was used only to keep the die in the right position in the vertical direction.

4. Tooling

The die set shown in Fig. 7 was designed to fulfil the functional and geometrical requirements of the machine and to provide adequate performance as an ECAP die. The former was realised by incorporating intermediate tool elements between the die with punches and the hydraulic actuators. These were the pushers driven by the internal actuators whose role was to push punches and limit their stroke and the guides pressed by the external actuators whose role was to guide pushers and transmit a horizontal fixing force. The latter was realised by using a segmented die insert prestressed with outer rings. There were five die segments in total. Two short ones on one side of the die, which created a gap for the billet exit, and one long on the opposite side of the die, which featured a profiled spike to facilitate material flow from the horizontal channel into the die exit. The remaining two segments served as the side walls for the channel defined by the above three segments. The outer rings were forced on the