

## VARIOUS POSSIBILITIES OF THE HOT EXTRUSION IN ALUMINUM CHIPS PROCESSING

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### Abstract

This article deals with the analysis and comparison of the conditions for solid state welding during extrusions by means of numerical simulation. Numerical simulations made on four different matrices, such as square die without integrated extrusion and equal channel angular pressing (iECAP), porthole die with one and four square profile. Maximum volume and distribution of effective strain, strain rate and shear stress was analyzing. The results show that during cold molding of chips there is mutual deformations of chips, which are rearranged and mechanically crimped. In the first phase of pressing occurs complete elimination of porosity. The square die with iECAP was extrusion force is 30% higher than porthole die. Maximum effective strain was calculated for the porthole die with four square profile.

**Keywords:** equal channel angular pressing, equal channel angular rolling, finite element method, microhardness

### 1 Introduction

Currently producing more and more products from light weight non ferrous materials mainly based on Al, Ti, Mg, Ni and Be, the manufacture of which there is a considerable amount of waste. This waste can be in the form of chips or scraps produced in the manufacturing process as die casting and plastic forming processes, especially metal machining. Most common recycling processes are remelting of chips or scraps. However, these processes are energy-intensive and inefficient, as these materials have a high affinity for oxygen. The shape and thickness of the particles depends on the method of working. Particles can be short from sawing or long and narrow from high speed machining, milling and turning operations [1-3].

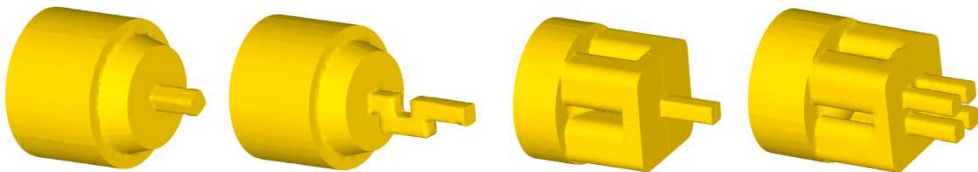
The hot extrusion process can be used to direct conversion of aluminum chips to final products. Several papers [4-6] reported that direct extrusion with a lower ratio of 12:1 is not sufficient to establish a coherent / fixed connection between the chips. Due to the implementation of a new technologies operation, such as SPD (severe plastic deformation), into forward extrusion process. They are in the molding process to ensure a high plastic strain by simple shear. To a continuous process forward fit is possible to implement a number of methods such as equal channel angular pressing (ECAP) [7-14], twist extrusion (TE) [15-17], or friction stir processing called as KOBO [18, 19]. Authors [6, 20] achieved superior bonding quality of chip-based extrudates by integrated aluminum extrusion and equal channel angular pressing (iECAP) at the

low extrusion ratio of  $\sim 8.7$ : first Well properties are achieved by extruding through feeder porthole die, with two or four feeder [4-6, 21]. Authors [4] reported that for the welding of the chips two criterions must be fulfilled. First the oxide layers must be broken down to allow virgin metal-to-metal contact and the second cumulative value of the ratio of the mean stress to the flow stress must be greater than a constant value. High plastic deformations are achieved when pressing hollow moldings, using porthole die.

This article deals with the analysis and comparison of the conditions for solid state welding during extrusions by means of numerical simulation. Numerical simulations made on four different matrices, such as square die without integrated extrusion and equal channel angular pressing (iECAP), porthole die with one and four square profile. Maximum volume and distribution of effective strain, strain rate and shear stress was analyzing.

## 2 Finite element modelling

Numerical simulation of forward extrusion chips were carried out using three different extrusion dies (**Fig.1**). The first one the square die (**Fig. 1a**) is conventionally used in industry for solid-sections product, the second one the square die with integrated equal channel angular pressing (iECAP) tool including the fourECAP steps (**Fig. 1b**) procedures using in severe plastic deformation (SPD), and the third one **Fig. 1 c,d** porthole die that is typically used to produce complex hollow and semi hollow profiles. Three dimensional finite element simulations of forward extrusion process were performed using the commercial software Deform 3D<sup>TM</sup> with Lagrange formulation.

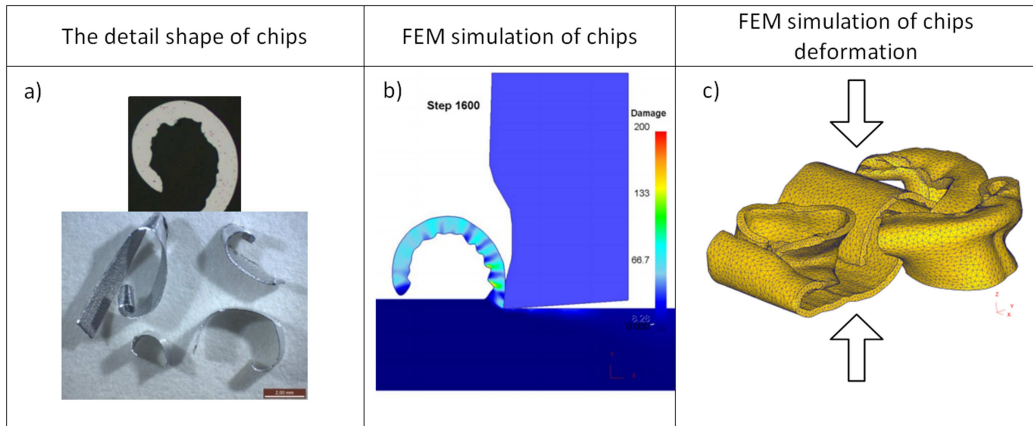


**Fig. 1** Schematic illustration of the three different extrusion process for solid state recycling of aluminum chips by hot extrusion, a) square die; b) flate-face die with iECAP; c) porthole die with one profile and d) porthole die with four profile.

The dimension of chip-based billets after cold compacted was used as in conventionally used in industry for solid-sections product. The diameter of chip-based billet was  $D_0 = 150$  mm with the length  $L_0 = 600$  mm. The resulting extrusion ratio (ER) for this profile is  $\sim 45:1$  and theoretical calculated the true strain after the extrusion is  $\ln(ER) \sim 3.8$ . In order to reduce the simulation time was for the first and third die model set up only the quarter model using two symmetry planes while the second model has only one symmetry planes. Number of tetrahedral finely element mesh for quarter dimension model was 90,000 elements and for two dimension 50,000. In the simulation was used the plastic material model for the billet. The commercially aluminium alloy AW 6061 was used from the database DEFORM, description by Johnson's - Cook model. The container, the die and the ram were assumed as rigid parts due to higher strength and remaining undeformed during process. Deformation temperature was  $520^\circ\text{C}$ . Friction conditions between the billets and the die was used the constant shear model  $\tau = 0.4$ . All simulations were carried out at a constant ram speed of 5 mm/s. Due to the large strains during simulations the adaptive meshing (automatic remeshing) was used.

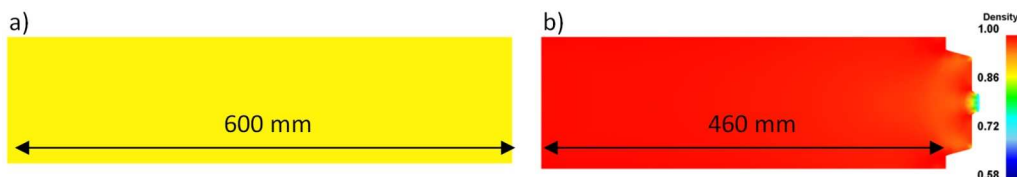
### 3 Result and discussion

**Fig. 2** shows the model simulation of chips cold pressing. Fig. 2a shows the shape of chips for high speed machining. Its shape was numerically simulated in 2D (Fig. 2b). Numerical simulation of compaction chips consisted of 5 randomly arranged chips gravity. As can be seen in Fig.2 at cold pressing of chips there is mutual deformations chips, which are mutually, rearrange and mechanically crimped. Mechanical connection is formed only. This process is dependent mainly on the shape and thickness of the chips. The compaction of the particles in the (semi) a pin are achieved varying bulk density of approximately 80% [4, 6], it is according to the size of the pre-product and compacting pressure.



**Fig. 2** Cold pressing simulation of chips

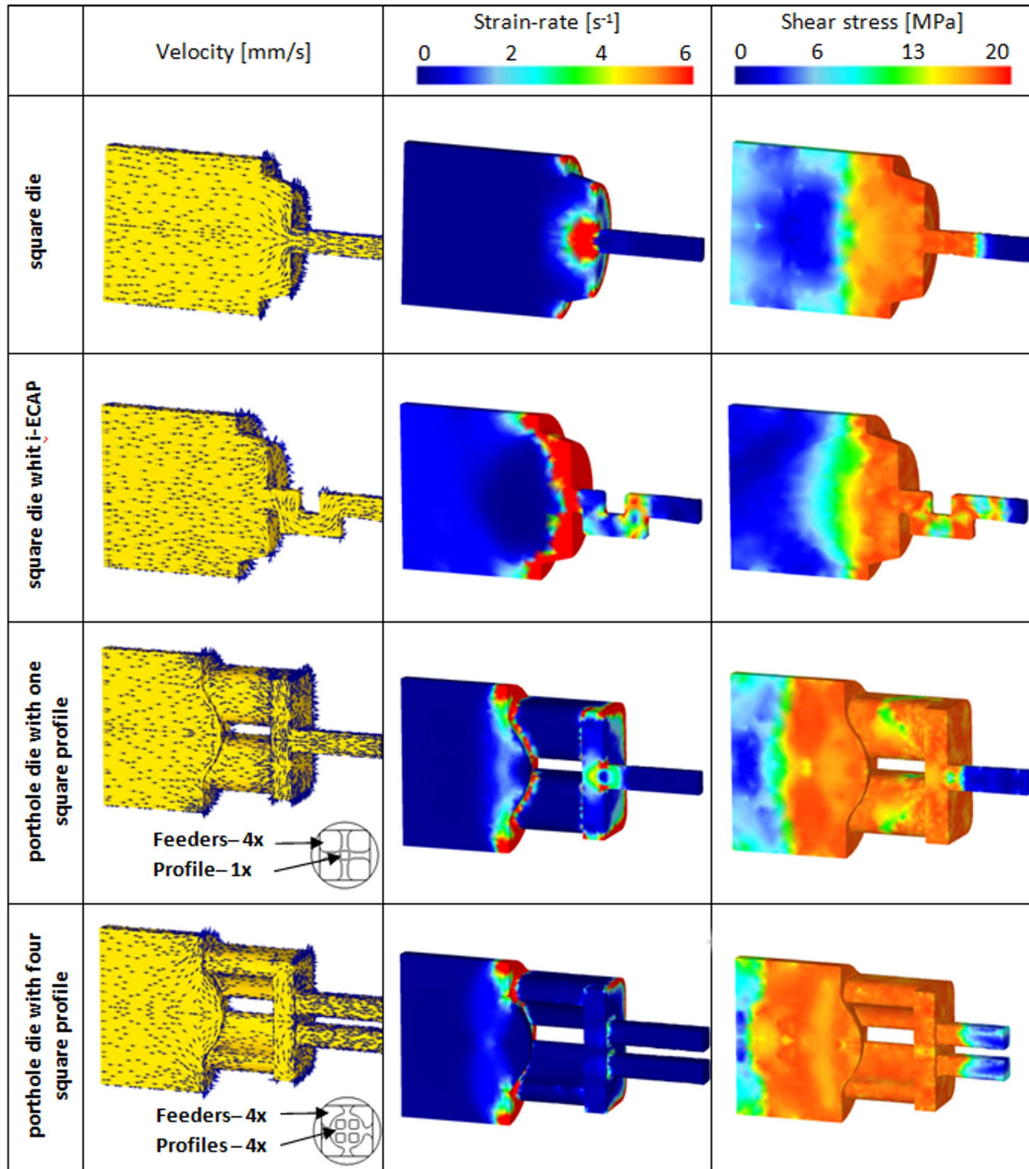
**Fig.3** displayed density change of chip billets during forward extrusion. In the simulation, the pin is defined as a porous material with a bulk density of 80%. As seen in Fig. 3, the first phase of chip billets pressing leads to complete elimination of porosity cause by the high hydrostatic pressure. This results was also documented by the authors [4].



**Fig. 3** Density change of chip billets during forward extrusion

The results of the FEM simulations can be seen in **Fig. 4**, where the velocity, strain-rate effective and shear stress distributions during the extrusion through the square die and porthole dies are shown on the middle plane of the extrusion.

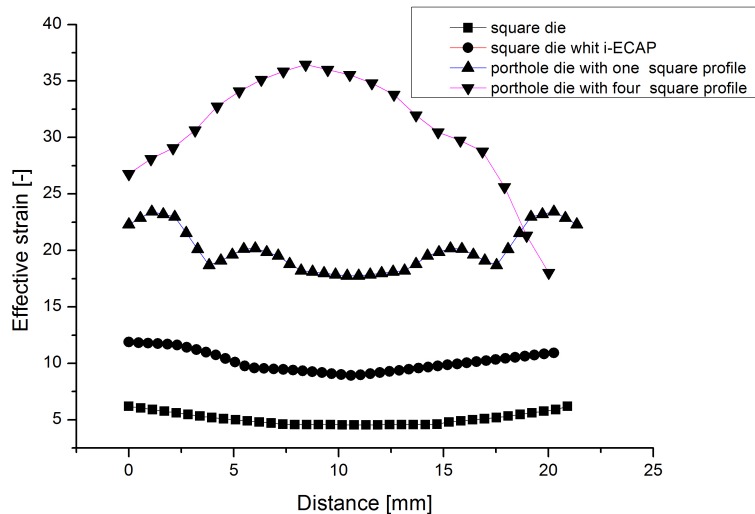
When square die deformation occurs first in the pre-chamber region. In the main deformation zone (MDZ) is seen intensive strain rate concentrated in a narrow field. Distribution strain after the effective thickness of the billet is shown in **Fig. 6**. Strain value reached effective deformation,  $\epsilon \approx 6$ , in the extrusion ratio 45:1. The extrusion force reached a value  $F \approx 1$  MN (**Fig. 5**).



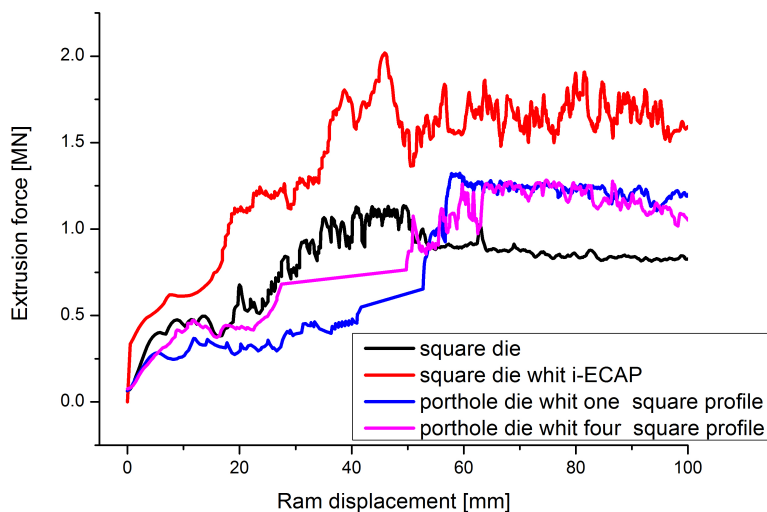
**Fig. 4** The stress-strain analysis of forward extrusion chips using three different extrusion dies

Implementation of the four ECAP steps leads to the generation of the natural back pressure in the ECAP channel [22]. Back pressure is also transmitted to the pre-chamber region, which causes turbulent flow of materials. Effective deformation is almost twice as high ( $\varphi \approx 10$ ) as in the previous case. In place of intersecting canals is the rate of deformation concentrated in the narrow band which promotes the formation of simple shear. Shear deformation contributes to disruption of oxide layers on the particles, and thus helps to a better diffusion connection of chips. Intensive plastic deformation in ECAP channels caused an increase in the extrusion force of nearly 1.7 MN (**Fig. 5**). The high value of the extrusion force has been well documented in

Article C. Plastic deformation in porthole die takes place in several places. First, the material is divided into four feeders and their ends are again combined and weld in welding chamber. To create a high shear stress, the area of the output profile to push feeders, as is schematically shown in **Fig. 4**. The complex material flow causes high effective strain, where porthole die with one profile is  $\varphi \approx 20$  and for porthole die with four profile is  $\varphi \approx 30$ . The extrusion force for both cases is very close to the value of  $F \approx 1.2$  MN.



**Fig. 5** Distribution of effective strain in cross-section of the extrude sample



**Fig. 6** The extrusion force vs. ram displacement curves.

#### 4 Conclusion

1. During cold molding of chips there is mutual deformations of chips, which are rearranged and mechanically crimped.

2. In the first phase of pressing occurs complete elimination of porosity.
3. The square die with i-ECAP was extrusion force is 30% higher than porthole die.
4. Maximum effective strain was calculated for the porthole die whit four square profile.

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