NUMERICAL COMPUTATIONS OF ALUMINUM PLATE SURFACE STRENGTHENING BY SEVERE PLASTIC DEFORMATION

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Introduction

Severe plastic deformation (SPD) is an important technique for fabrication of bulk materials with ultrafine grain sizes. SPD has attracted a great deal of attention over the past two decades because of the materials' enhanced properties [1, 2].
In the past decade, a number of the various sever plastic deformation (SPD) techniques have been used to refine structure of metals and alloys. To introduce large plastic strain into bulk material, different techniques have been used such as ECAP [1], high pressure torsion (HTP) [3], accumulative roll bonding (ARB) [4, 5], constrained groove pressing (CGP) [6], and others. All above mentioned techniques are designed to produce submicron- and nano-grained materials in entire volume of bulk material.
The aim of authors of this research work is to find a technique which could introduce a large plastic strain into surface or selected areas of bulk material. Work-piece after processing has ultrafine grain structure on one surface plane and slightly deformed structure in the rest of material.
Accumulative surface forming (ASF) was proposed to reach this aim. Technique is schematically shown in Fig.1. Material would flow behind the cog as soon as die cavity is filled in direction of mandrel's movement and the die reaches its elastic limits. Process is repeated until the ultra fine structure is reached.

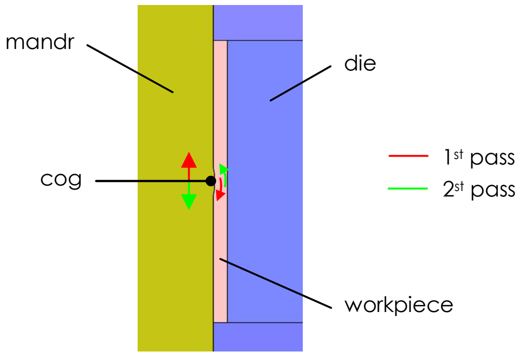

Fig. 1 Principle of ASF process.

Numerical simulation using Finite Element Method (FEM) was chosen for finding an optimal geometry of tools for aluminium processing under various process conditions.

The FEM is a proven and reliable technique for analyzing forming processes, and has been widely used for various forming operations [7]. The method provides detailed information concerning the distribution of strains, strain rates, stresses and material flow, as well as the necessary external loads. Thanks to this information recommendations on tool geometry and processing conditions can then be provided.
The purpose of this work is to find optimal geometry and construction of ASF die for aluminium plate subjected to the large strain during cold processing.

Experimental procedure

In view of ASF optimisation, it is of prime importance to assess the relationships between processing conditions and material flow. More precisely, detailed knowledge of the plastic strain distribution in the processed material in relation to the processing variables is required. The key parameters of the ASF process are primarily die geometry and its rigidity, geometry of mandrel with cog, stiffness of assembly, forming temperature, friction conditions and number of forming passes.

Material
Common 99,8 % aluminium was chosen as experimental material. Material data necessary for numerical simulation was taken from the DEFORM material library. Work-piece was considered as plate with dimensions: 100 x 100 x 5 mm.

Software and simulation versions
DEFORM 2D commercial package was used for optimisation of mandrel geometry.
DEFORM 3D commercial package was used for testing of die rigidity and overall assembly stiffness.
List of simulation variants is shown in Table 1.

Table 1 Simulation variants.

Simulation name	Software	Cog overhang [mm]
ASF_2D_06	DEFORM 2D	0,6
ASF_2D_05	DEFORM 2D	0,5

ASF_2D_04	DEFORM 2D	0,4
ASF_3D_04	DEFORM 3D	0,4

Results and Discussion

Effective stress peaks of die during the first pass and the maximum effective strain values reached in the material after the first pass are summarised in Table 2.

Table 2 Simulation results – stress and strain comparison.

Simulation name	Stress peak [MPa]	Max. Strain [-]
ASF_2D_06	204	0,65
ASF_2D_05	179	0,58
ASF_2D_04	146	0,45
ASF_3D_04	130	0,42

It was found that the cog overhang has significant influence on both maximum strain value and the depth of strain affected area. Effective strain distribution in material after the first pass is shown in Fig.2.

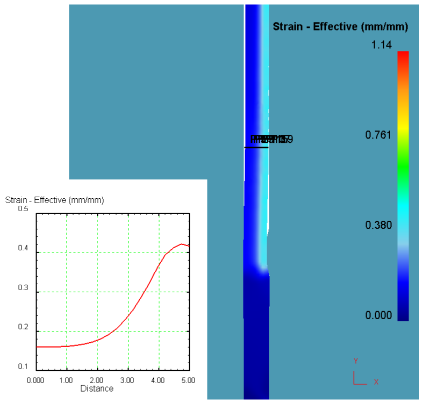

Fig. 2 ASF_2D_05: Effective strain in work-piece after the first pass.

The shape of the work-piece after processing is strongly affected by elastic deformation of tools. Material flow begins with the filling of continuously elastically enlarging die cavity in the direction of mandrel movement. Material starts to flow counter wise to movement of mandrel as soon as an elastic load of die is higher than flow stress of material (Fig.3).

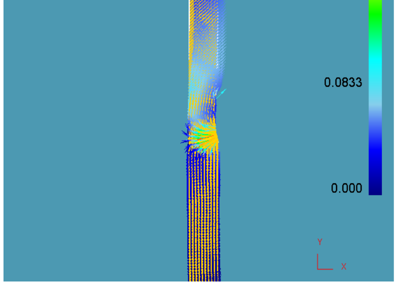

Fig. 3 ASF_2D_05: Material flow during the first pass.

Elastic deformation of tools leads to creation of gap behind the cog (see Fig.2) where effective strain addition is decreased during the next pass. The length of gap is a function of tool elastic deformation and the initial geometric inaccuracies.

Simulations in 2D shown very high loading of tools especially before end of each pass. In order to decrease stress peaks sectional die was designed. Full 3D analysis was carried out to test loading of designed assembly under process conditions and compares it with original one-piece die design. Distribution of effective stress is shown in Fig.4.

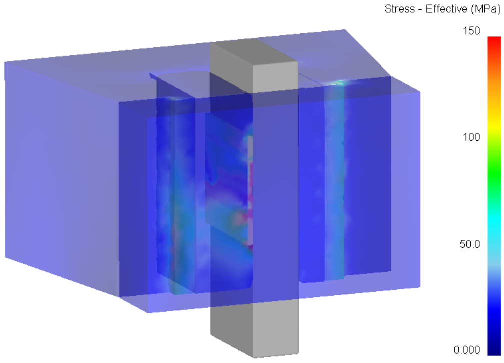

Fig. 4 ASF_3D_04: Loading of assembly during the first pass.

Conclusion

Feasibility of proposed Accumulative Surface Forming (ASF) technique was investigated by means of FEM. Simulated variants shows significant influence of cog overhang on loading of die and mandrel. Usage of sectional die effectively decreased stress peaks.

To ensure feasibility of ASR technique the high strength tool material with as low as possible Young module, preferably under pre-stressed conditions, should be chosen. Geometry of tools and work-piece should be manufactured with very tight tolerances to maximise accumulation of strain in formed material.

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