

Parameter optimisation for a fan-shaped extrusion in AZ31 magnesium alloy

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Introduction

In recent years, more attention has been paid to the forming process of wrought magnesium alloys since most structural components made from magnesium alloys, such as sheets, bars, pipes and profiles, can only be produced by plastic deformation. However there are still many problems in the extrusion process to produce profiles, especially high precision profiles, in magnesium alloys. For example, defects such as splits, folds and distortions may occur in the extrusion process. In this study, numerical simulation, based on the Finite Element Method (FEM), combined with the orthogonal experimental method, has been conducted to investigate the effect of various parameters, such as the extrusion ratio, extrusion temperature and extrusion speed, on the extrusion process of a fan-shaped profile of a magnesium alloy AZ31. Optimal parameters are obtained according to the stress state results which can obviously decrease the formation of defects. Microstructural analyses on the extruded alloys have also been undertaken to verify the reliability of the numerical analysis.

Equivalent stress simulation analysis of products at the die exit

Optimal extrusion parameters

Numerical simulation model

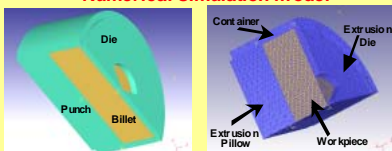


Fig. 1 Extrusion 3-dimensional and 1/2 FEM simulation model.

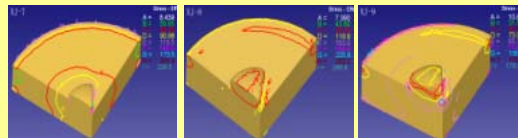
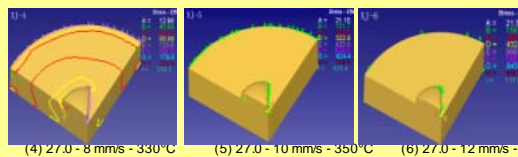
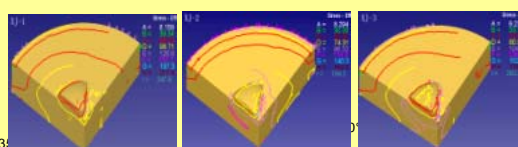
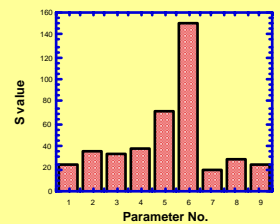


Fig. 3 Effective stress contour maps for different extrusion parameters (ratio-speed-temperature). Curves with different colors represent the distribution of different effective stress values shown on the top right corner of each figure.



$$S = \sqrt{\frac{\sum_{i=1}^N (\sigma_i - \bar{\sigma})^2}{N}}$$

$$= \sqrt{\frac{(C \cdot \frac{C_0 D_0 E}{3})^2 + (D \cdot \frac{C_0 D_0 E}{3})^2 + (E \cdot \frac{C_0 D_0 E}{3})^2}{3}}$$

Fig. 4 Histogram of S value (mean-square deviation of the effective stress), calculated based on the results shown in Fig. 3.

The optimal extrusion processing parameters are corresponding to the smallest S value, which represents the level of inhomogeneous stress distribution. FEM simulation results suggest that it is at condition No. 7:

Extrusion ratio = 18.4
Extrusion speed = 8 mm/s
Extrusion temperature = 350°C

The as-cast microstructural intermetallic particles there was a coarse and uneven distribution of α -Mg grains, together with a relatively uniform distribution of fine particles (~35 nm) within the α -Mg, Fig. 5(b). After the second extrusion, there was a significant reduction of α -Mg grain size and an obvious decrease in the particles size (~25 nm), Figs. 5(c) and (d). Although the overall grain size in the alloy under the extrusion parameter No. 7 (Fig. 5(c)) was coarser than that of parameter No. 5 (Fig. 5(d)), the size distribution of the α -Mg grains was more uniform. This appears to be associated with the significantly lower S value under the parameter No. 7, shown in Fig. 4, which represents the lower level of an inhomogeneous stress distribution (i.e. less stress concentration). Fan-shaped bars extruded under the optimal parameter No. 7 were of an excellent quality, Fig. 5(e).

Speed simulation analysis of products at the die exit

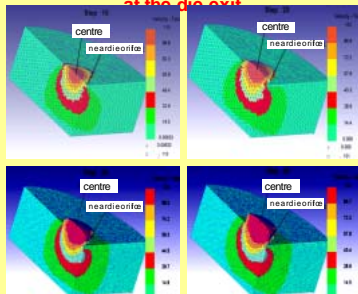


Fig. 2 Shear distortion and velocity contour of the extrusion step.

The metal flow velocity in the centre is larger than that near the die orifice, and their difference decreases with increasing incremental steps.

Both the effective stress distribution and its inhomogeneous level on the cross section of the billet are different under the different extrusion parameters when the billet is extruded away from the die exit.

Extrusion microstructures

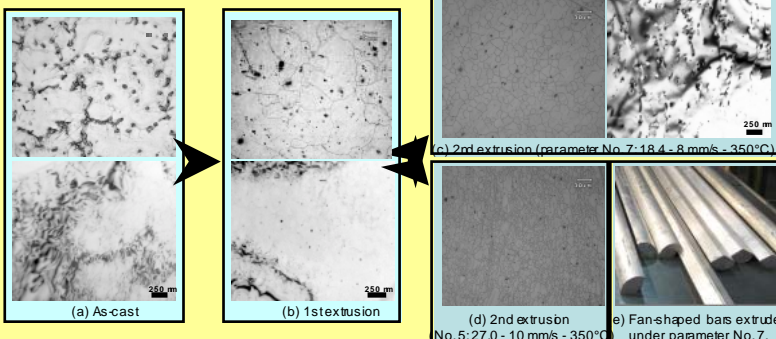


Fig. 5 Optical and TEM photos showing microstructures of the AZ31 alloy at different stages in the extrusion process.

Summary

Numerical simulation, based on the Finite Element Method (FEM), has been conducted to investigate the effect of extrusion parameters, on the extrusion process of a fan-shaped profile of a magnesium alloy AZ31. It is found that the optimal extrusion processing parameters are at extrusion ratio of 18.4, extrusion rate of 8 mm/s and extrusion temperature of 350°C, which is corresponding to the lowest level of inhomogeneous stress distribution. Microstructural analysis of the fan-shaped extrusion bars processed with the optimal extrusion parameters shows it has a more uniform size distribution of the α -Mg grains, which can significantly decrease the amount of defects in the products and improve the productivity.