Numerically-aided selection of process parameters enhancing plasticity of magnesium alloy in warm forging

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Abstract. The paper presents an innovative precision forging process, highlighting the use of advanced simulation of net-forging process in multiple-tool die set with consideration of counter-pressure and interaction of components so as to control speed and displacement of metal flow. In addition to the use of finite element method in optimization of process conditions, damage criteria have been formulated to investigate the effect on plasticity and tendency of formation of defects and define process conditions which contribute to cracking occurrence in warm forging of magnesium alloy AZ61.

INTRODUCTION – MOTIVATION AND SETBACKS IN FORGING Mg ALLOYS

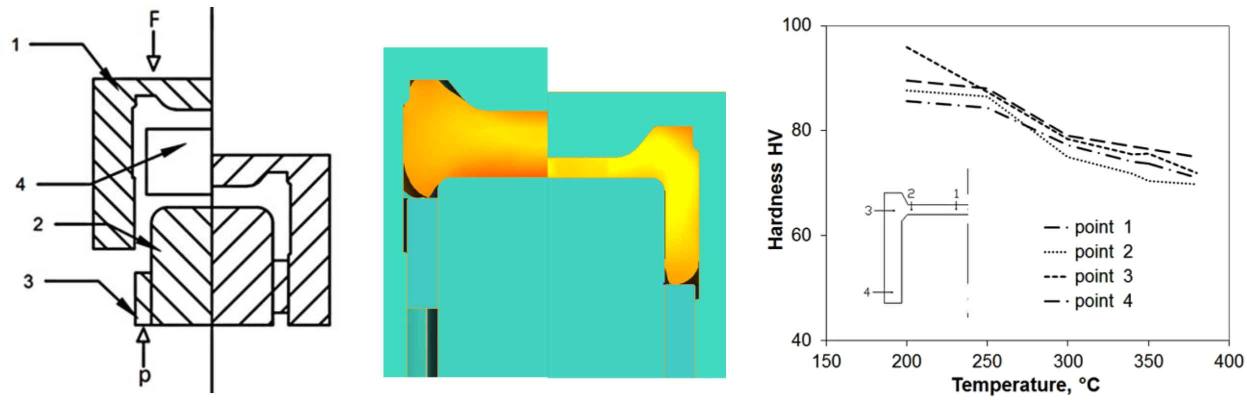
Specific advantages of magnesium alloys are generally known. So are their disadvantages and limits in potential civil, transport, military or aircraft engineering applications. Extensive studies have been carried out over last decades with efforts to improve their key features. Although it is obvious that these features, especially increased temperature stability of strength and corrosion resistance, rule out Mg alloys from high-duty and responsible applications, a number of new field of use emerges, e.g. sport and recreation, where lightness and response to high and low temperature or dimensional stability can compete with polymers, especially if plastic-formed magnesium wrought alloys are considered. Cold or warm deformation is one of the most effective in strengthening of Mg alloys [1]. However, due to low intrinsic workability in low homologous temperature Mg alloys need plasticity enhancement to undergo plastic deformation. Hydrostatic extrusion or equal channel angular extrusion are most common in that respect, however, cross-section and sizes are limited, as well as, extruded geometry calls for mechanical finishing [2]. On account of flammability at increased temperature generated during machining and reactivity to water (potential coolant), net shapes can be readily cast, which reduce the possibilities of strength enhancement to chemistry, reducing range of application or more rarely, forged.

Forging is the process where complex state of stress and locally high strain-rate concentrations enhance both difficulties related to low workability and benefits associated with considerable reduction and favourable grain flow promoting directionality of properties [3]. Both of the factors must be taken into consideration in design of forging technique and controlled.

GOAL OF THE STUDY AND RESULTS

The presented work incorporates abovementioned conditions into net forging process to allow for low allowance shaping of thin-walled products featured by high strength by means of control of state of stress components. Employing counter-pressure-driven floating inserts (Fig.1b) enable forging at relatively low temperature on high-speed forging equipment, if the kinematic and geometrical parameters are properly set [4]. To establish proper process conditions numerical modeling with finite element method (FEM) is helpful, as long as it is possible to properly define kinematic parameters and boundary conditions in the numerical model [5]. The paper presents use of advanced simulation of forging process, including interaction of components in multiple-tool die set with consideration of counter-pressure so as to control speed and displacement of metal flow (Fig.1b), which turned out the key factor in proper metal flow resulting in flawless forging. Its effect on plasticity and tendency of formation of defects is diagnosed by implementation of damage criteria, which allow localize onset of cracking and process conditions which contribute to its occurrence.

The numerical analyses put into practice allowed verification of the assumptions and calculations, as well as enabled realization of warm forging tests of AZ61 Mg alloy. The tests showed obvious effect of counter pressure on plasticity and validated calculated dependence of this parameter on temperature related flow stress. The forged samples obtained in physical realization of the process confirmed the assumed plasticity enhancement which makes it possible to produce sound forgings of magnesium alloy AZ61 at high forging speed, and showed possible effect on mechanical properties (Fig. 1c) as well as on energy balance of the forging process.



(a) (b) (c)

FIGURE 1. Graphical summary of the study: scheme of forging die set before and after forging (a), where 1-3 – die inserts, 4 – billet, F, p – working pressures, numerical model of the process (b), material strengthening effects (c)

CONCLUSIONS

Magnesium alloy are hard to deformation at warm and cold temperature. Application of split dies with floating insert regulated by pressure balance enabled screw forging of AZ61 in warm-forging range, thus high-strength thin-walled precision forging were obtained. key issue in this effort was the control of pressure balance between material and floating die. The use of coupled thermo-mechanical analysis with interaction of components in multiple-tool die set, numerical simulation with FEM allowed selection and optimization of the process variables, especially set the optimal value of counter-pressure, which is crucial for the soundness and precision of the final product. Geometrical similarity to numerous engineering components or their sections make the guidelines representative and valid for wide range of applications.

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