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PHYSICAL MODELLING AND NUMERICAL FINITE ELEMENT METHOD (FEM) SIMULATION OF FORGING IN OPEN DIE OF ALLOY AlMgSi0,5

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This paper researches the process of forging in open die of gradual axial-symmetric workpiece made of alloy AlMg-Si0,5. The physical modelling was carried out, for which an original method for physical discretisation and numerical FEM analysis was developed. The components of tensor were determined: strain, strain rate, stress and the corresponding effective parameters. The results obtained experimentally and through a numerical FEM simulation were compared and analysed.

Key words: forging, Al alloy, strain rate, stress, modelling, numerical simulation

INTRODUCTION

A numerical simulation following the finite element method (FEM) is widely used today. The application of the method is constantly being updated with increasing simplicity of use, the development of up-to-date software, a reduction in the time necessary for the preparation of input data and obtaining a wide spectrum of exit information. Beside this, the question always arises whether the input parameters were correctly taken and if the obtained results were valid [1]. For that purpose, an original method of physical discretisation was developed, which is used to verify numerically obtained results. The values determining the process of deformation were researched: displacements, strains, displacement velocities, strain rates and stresses.

This paper further shows an experimental method of modelling, a numerical FEM simulation and the comparison of the obtained results.

PHYSICAL MODELLING

The definition of the experiment

The research was carried out in laboratory conditions and attuned in such a way to be as similar as possible to the condition of production.

An axis-symmetric gradual processing piece with two levels of height on the upper and one level of height on the lower side of the partition plane was adopted, Figure 1 [2].

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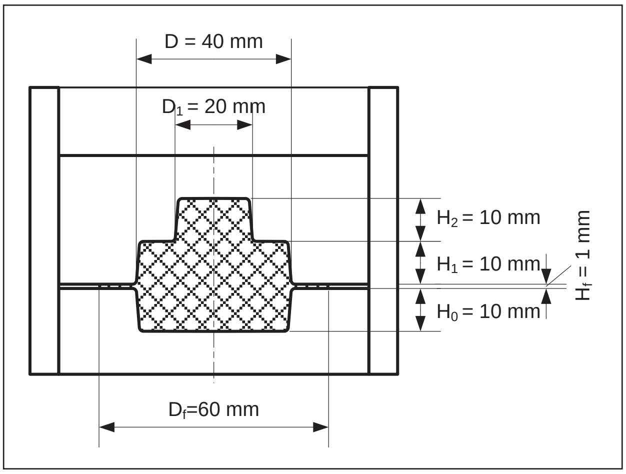

Figure 1 System: tool – workpiece [2]

An aluminium alloy AlMgSi0.5 was used as a testing material and its chemical composition is given in Table 1.

Table 1 **Composition of alloy AlMgSi0,5/wt. %**

Fe	Si	Ti	Cu	Zn
0,207	0,477	0,01	0,09	0,068
V	Cr	Mn	Mg	Ni
0,004	0,01	0,1	0,493	0,02

The testing is carried out at the temperature of hot processing: t = 440 °C. The deformation is accomplished with a constant deforming velocity: v = 2 mm/s. Graphite grease was used for the lubrication.

An upper and lower die were used as tools, Figure 1, put in a slideway which provided their coaxiality and had the role of a chamber for the maintenance of temperature constancy. The slideway was heated together with the dies and specimens.

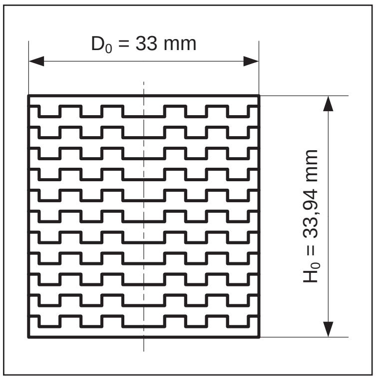

Figure 2 Segmented specimen

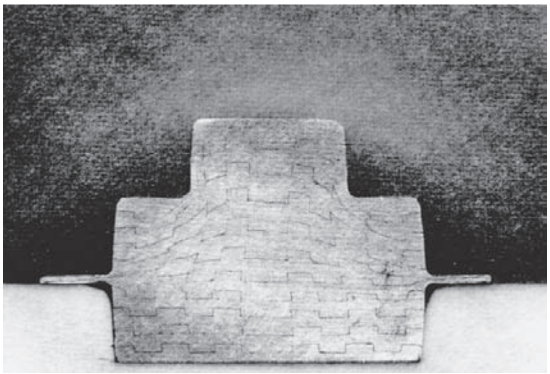

Figure 3 Deformed mesh

The dies were made of tool steel for hot work designated as X38CrMoV-5-1 [3].

The specimens have the following dimensions: ∅ $d_0 \times h_0$ = (33 × 33,94) mm. The height of the specimen is calculated from the condition of constancy of volume.

For the execution of strain, strain rate and stress analyse of the working piece in a meridional cross-section, physically discretised specimens consisting of adequate segments were made. The physical discretisation of each specimen ensures that, after the process of deformation in open dies, thanks to the adequate preparation of the specimen, the displacements of the characteristic points on the cross-section can be measured. During the experimental research based on the idea of physical discretisation, it was ascertained that the best results are obtained when the specimen consists of grooved plates, Figure 2.

In such specimens, the grooves in the plates in a meridional cross-section actually form a mesh of finite elements, whose elements are determined of four nodes and three lines, thus it is possible to determine the displacements of the nodal points both in a radial and in an axial direction.

The segmented specimens, behaving in a compact manner in all phases of the process, are obtained from such designed groove plates.

Determination of strains

After the process of the metal formation of segmented specimens and the cooling of the processed pieces, one half up to the meridional cross-section was removed and the processed surface was polished. This surface was corroded using a 30 % water solution of NaOH, which made the deformed contours of the groove plates clearly visible Figure 3.

The figure of a non-deformed mesh of the radial cross-section of a specimen was obtained in the same way Figure 4.

To determine the parameters of the state of strain, it was necessary to determine the numerical values of the nodes in the deformed mesh (from Figure 3), Figure 5.

The displacements of points both in the radial and axial direction were determined on the basis of the known numerical values for the node coordinates in the non-deformed and deformed meshes:

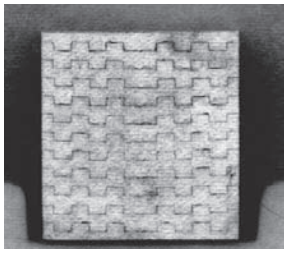

Figure 4 Non-deformed mesh

$$\left.\begin{aligned} u_r &= r - r_0 \\ u_z &= z - z_0 \end{aligned}\right\} \qquad (1)$$

where: u_r, u_z – displacements in the radial and axial direction at the end of the process,

r, z – coordinates of the nodal points at the end of the process,

r_0, z_0 – coordinate of the nodal points at the beginning of the process.

In this way, it is possible to determine the partial derivations of the displacements for the radius and height, which can serve to allow us to obtain the values of strains [4].

Then, the effective strain was determined:

$$\varepsilon_e = \frac{\sqrt{2}}{3}\sqrt{\left(\varepsilon_r - \varepsilon_\theta\right)^2 + \left(\varepsilon_\theta - \varepsilon_z\right)^2 + \left(\varepsilon_r - \varepsilon_z\right)^2 + \frac{3}{2}\gamma_{rz}^2}, \qquad (2)$$

where: ε_r, ε_θ, ε_z – normal strains in radial, tangential and axial direction,

γ_{rz} – shear strain.

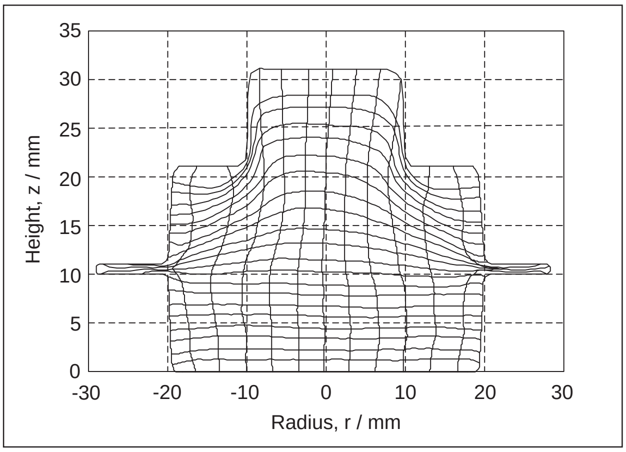

Figure 5 Numerical values for nodes of deformed mesh

Determination of strain rates

The determining of the displacement velocity represents the basis of kinematic analyse. Given that the process of deformation in open dies is a non-stationary process, the strain rates are calculated on the basis of the displacements of points at the beginning and at the end of the finite interval of a strain at the end of the process, under the assumption of a constant deformation velocity. This interval must be small enough to express a correct state of the strain rates, but not too small, in order to avoid the influence of the anisotropy of a deformation. During the preliminary experiments, it was ascertained that the optimal interval of a strain at the end of the process of strain for the increase of the tool step $\Delta z = 2$ mm.

At the beginning of the adopted strain interval, it was necessary to identify the deformed mesh of the specimen's meridional cross-section. The process of deformation was ceased for the height of the flash of $h_f =$ 3 mm. The preparation process of the specimen's cross-section surface was the same as for the determination of the strains, Figure 6.

The displacements of points in a radial and axial direction were determined on the basis of the known values of the coordinates for the nodal points of the non-deformed and deformed mesh at the beginning of the observed interval:

$$\left.\begin{aligned} u_{ra} &= r_a - r_0 \\ u_{za} &= z_a - z_0 \end{aligned}\right\}, \qquad (3)$$

where: u_{ra}, u_{za} – displacements in the radial and axial direction at the beginning of the observed interval of the strain,

r_a, z_a – coordinates of the nodal points of the mesh at the beginning of the observed interval of strain.

The increment of displacements in nodal points of the deformed mesh was calculated as the difference between the displacements at the end and at the beginning of the observed interval.

Bearing in mind that the forming velocity is constant and is v = 2 mm/s, and for the adopted increment of the tool step $\Delta z = 2$ mm, the increment of time is $\Delta t = 1$ s.

On the basis of the values of increments of displacement for the nodal points of the deformed mesh of the meridional cross-section and the time of the interval duration, it is possible to determine the components of the displacement velocity.

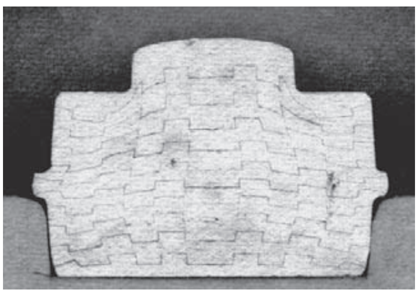

Figure 6 Deformed mesh at the beginning of the interval

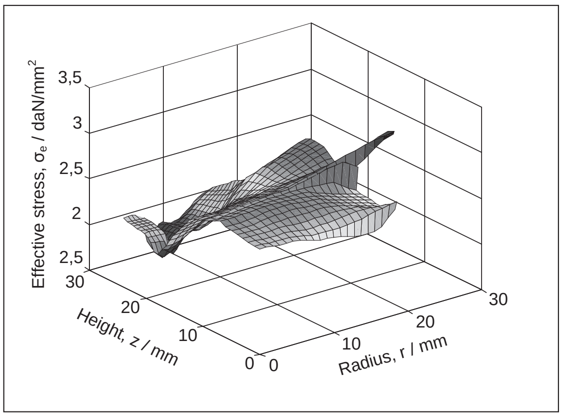

Figure 7 Effective stress

For the known values of the displacement velocities, the partial derivations of displacement velocities for the radius and height, which serve for the calculation of strain rates, were determined. The effective strain rate was calculated as follows [4]:

$$\dot{\varepsilon}_e = \frac{\sqrt{2}}{3}\sqrt{\left(\dot{\varepsilon}_r - \dot{\varepsilon}_\theta\right)^2 + \left(\dot{\varepsilon}_\theta - \dot{\varepsilon}_z\right)^2 + \left(\dot{\varepsilon}_r - \dot{\varepsilon}_z\right)^2 + \frac{3}{2}\dot{\gamma}_{rz}^2}, \qquad (4)$$

where: $\dot{\varepsilon}_r$, $\dot{\varepsilon}_\theta$, $\dot{\varepsilon}_z$ - normal strain rates in radial, tangential and axial direction,

$\dot{\gamma}_{rz}$ - shear strain rate.

Calculation of stress

The components of the stress tensors were determined using the method of visioplasticity on the basis of the equations of Levy-Mises. The fundamental equation of visioplasticity is [4, 5, 6]:

$$\frac{\partial \sigma_z}{\partial r} = \frac{2}{3}\sigma_e\left[\frac{\partial}{\partial r}\left(\frac{\dot{\varepsilon}_z - \dot{\varepsilon}_r}{\dot{\varepsilon}_e}\right) - \frac{\dot{\varepsilon}_r - \dot{\varepsilon}_\theta}{r\dot{\varepsilon}_e} - \frac{1}{2}\frac{\partial}{\partial z}\left(\frac{\dot{\gamma}_{zr}}{\dot{\varepsilon}_e}\right)\right], \qquad (5)$$

where: σ_z - normal stres in axial direction,

σ_e - effective stress.

Figure 7 presents a 3D diagram of the effective stress.

NUMERICAL FEM SIMULATION

The numerical simulation using the finite element method was carried out by the DEFORM software, specifically using DEFORM-2D, which is dedicated to the analysis of planes and axis-symmetric deformation. The necessary data for a FEM DEFORM simulation are: the geometric parameters of the working piece, the friction, the curve of flow and thermal parameters [7]. The change in the effective strain obtained by FEM simulation is given in Figure 8.

COMPARISON OF RESULTS

The 3D diagrams in Figure 7 and Figure 8 are suitable only for the visual observation of the change, while the 2D diagrams of the change in the parameters obtained experimentally- the physical modelling and the FEM simulation for the cross-section of the partition plane (Figures 9 - 11) are suitable for their quantitative comparison.

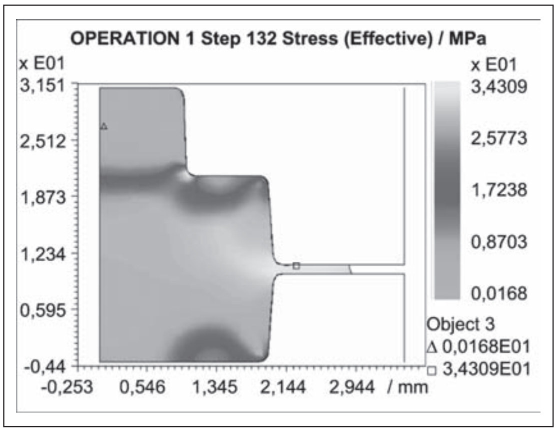

Figure 8 Effective stress (FEM)

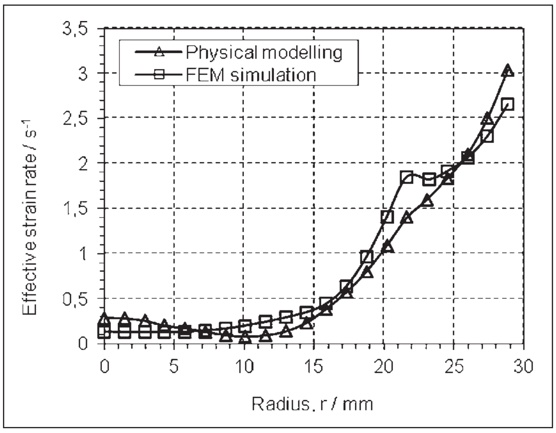

Figure 10 Effective strain rate

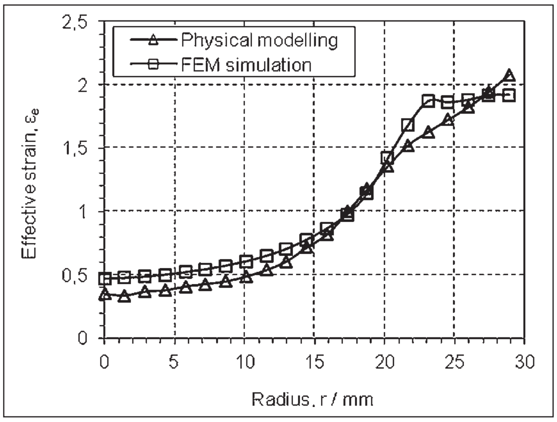

Figure 9 Effective strain

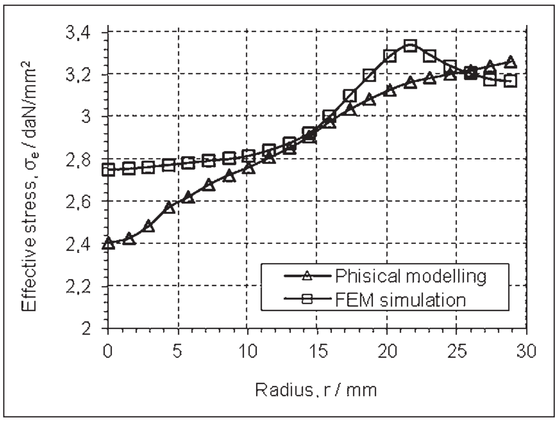

Figure 11 Effective stress

CONCLUSION

This paper examines forging in open die using three approaches: theoretical, experimental and numerical. The results of the numerical simulation are verified by physical modelling, using the originally developed methods of physical discretisation.

The numerical and experimental results for the components of tensor: strain, strain rate, stress and corresponding effective parameters were compared.

For an effective logarithmic strain which is in the interval 0,28 - 2,08 the biggest deflection is for the lowest values that are in the axis of the processed piece (25,5 %) and values corresponding to the middle of the flash (12,8 %).

The effective strain rate has low values inside the die (0,13 s^{-1}) and a good overlapping of results, while the deflection of results occurs at the place immediately behind the transition of the die into the flash an is 24 %. The maximal value of the effective strain rate is 3,04 s^{-1}.

The values of the effective stress are in the interval (2,4 - 3,34) daN/mm^2 and these results overlap well on the entire cross-section; the biggest deflections are in the vicinity of the axis of symmetry (12,7 %) and immediately following the transition of the die into the rim (5,38 %), which is the aftermath of the deflection of strains and strain rates in these places

The above-mentioned experimental analysis of the physical modelling gives results proving the validity of the results from the numerical FEM analysis for the given forging in open die of the alloy AlMgSi0.5 and the input parameters used.

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