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MODELLING OF NEAR-NET FORGING OF THIN-WALLED PARTS OF STRAIN RATE SENSITIVE ALLOY

1. INTRODUCTION

Conventional technologies of precision forging usually involve forging at a room temperature or at slightly elevated temperature. These are cold or warm forging processes. In case of exceptionally complex designs, which would involve several metal forming operations while manufacturing, hot-die forging or isothermal forging processes are used, sometimes taking advantage of superplastic properties of a deformed alloy [1].

Although the principle of cold forging and forging of compact materials does not often differ from the above mentioned techniques, the notion of precision forging refers to closed-die forging processes in die sets of special design. The main principle is to obtain finished part with proper mechanical properties with no machining allowances and minimum costs consideration.

Precision forging in superplastic conditions compared to conventional forging has lower production rate. Additional disadvantage is the necessity of using special heating systems both for heating of metal and tools, which calls for selection of special heat resistant materials for dies. Selection of proper die material depends on the working temperature, level of forging pressures, dwelling times and the exploitation period.

In this work the problem of precision forging of complex configurations was analysed using an example of a turbine impeller forged as one-piece with blades. On the strength of numerical modelling with Qform 3D commercial code a several alternative technologies were analysed. Four characteristic cases were studied, varied by temperature and forming speed. Minimum costs of tooling, labour costs and possibility of obtaining sound product characterised by proper operational properties at reduced material losses [3].

The estimation of the correctness of a process was based on the maps of effective strain distribution, effective strain rate distribution and mean stress distribution, with load observed while forging taken into regard.

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2. DESIGN CONSIDERATIONS OF A MODEL PART

On the basis of previously published papers on this problems it can be concluded that materials of increased strain rate sensitivity are characterised by capability of more uniform filling out die cavities, if determined conditions are fulfilled, including very slow rate of straining [1]. This condition can be hard to be fulfilled while forming parts of complex shape and parts of changing sections. Studies of the forging process of a part with significant changes of cross sections, and resultant large gradient of strain rate, were carried out for the model of impeller show in Figure 1. Forging of this sort of a part, is typically realised in the process of lateral extrusion. In the region of a hub the metal flow is relatively slow compared to the metal flow velocity in the regions of blades.

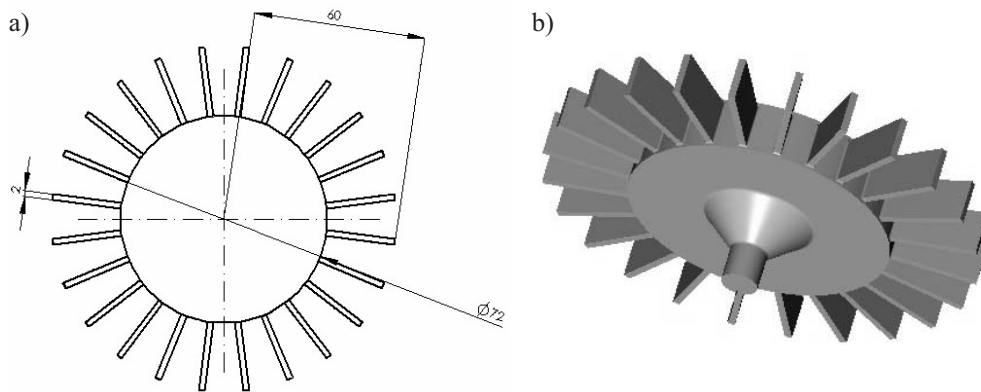


Fig. 1. Dimensioned sketch of the forging of radial bladed impeller (a) finished part (b)

Manufacture of such a part in conventional forging technologies is associated with serious setbacks or practically unfeasible. Employing strain rate sensitive materials, such as superplastic materials, makes it possible to produce such parts, however, appropriate strain rate must be provided [3].

In order to determine the most favourable conditions for forging the impeller, numerical calculations for four alternative technologies were performed, mainly, three variants of isothermal forging differing in forming speed of tools, and hot-die precision forging. Major dimensions of the part are shown in Figure 1a, and the shape of the forging – in Figure 1b. It was assumed that the forging process was one-stage forging operation of cylindrical billet in a die-impression shown in Figure 2. To provide isothermal conditions, heating of dies is assumed.

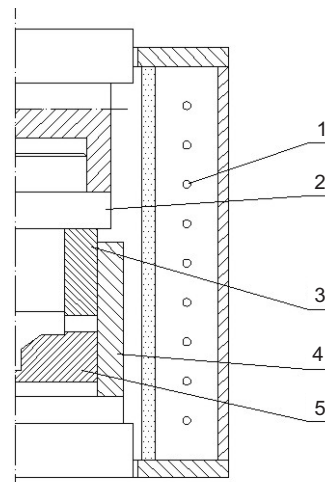


Fig. 2. Scheme of tooling for isothermal forging: 1 – heating system, 2 – punch, 3 – centering pad, 4 – ring, 5 – die

3. THE RANGE OF NUMERICAL CALCULATIONS

On account of the main goal of the work, that is, estimation of filling die-impression in the areas of impeller blade (Fig. 1a), the range of numerical calculations included effective strain distribution, effective strain rate distribution, mean stress distribution, and the level of forging pressures. Calculation were performed with a code Qform3D assuming rigid-viscoplastic model of deformed body [3]. The process conditions taken into consideration in the calculations were the forging equipment characteristics, grade of alloy, temperatures of tools, environment and temperature of heating the billet, frictional conditions at the contact surface tolls/metal, and emission and heat transfer coefficients.

Geometry conditions include the configuration of a workpiece and tools. The design of dies enables flashless forging, and any possible excess of material is compensated by the height of a boss. The calculations were made for high-melting Ni alloy. The rheological characteristic of this alloy, the function of flow stress versus natural strain for at a few temperatures and a few strain rates is shown in Figure 3. Flow stress values in function of strain for three different strain rates (10^{-4} s^{-1} , $5 \times 10^{-3} \text{ s}^{-1}$, $5 \times 10^{-2} \text{ s}^{-1}$) and three temperatures (700°C , 800°C , 900°C) were plotted according to criteria listed in the work [2, 4].

It was assumed that all of the analyzed forging processes started at 800°C temperature of the billet. In all cases the same friction conditions (friction factor 0.4) and environment temperature 20°C . Three values of velocity of the ram were assumed: 500 mm/s, 1 mm/s and 0.001 mm/s, and for 500 mm/s velocity, two variants of the tool temperature: 300°C and 790°C .

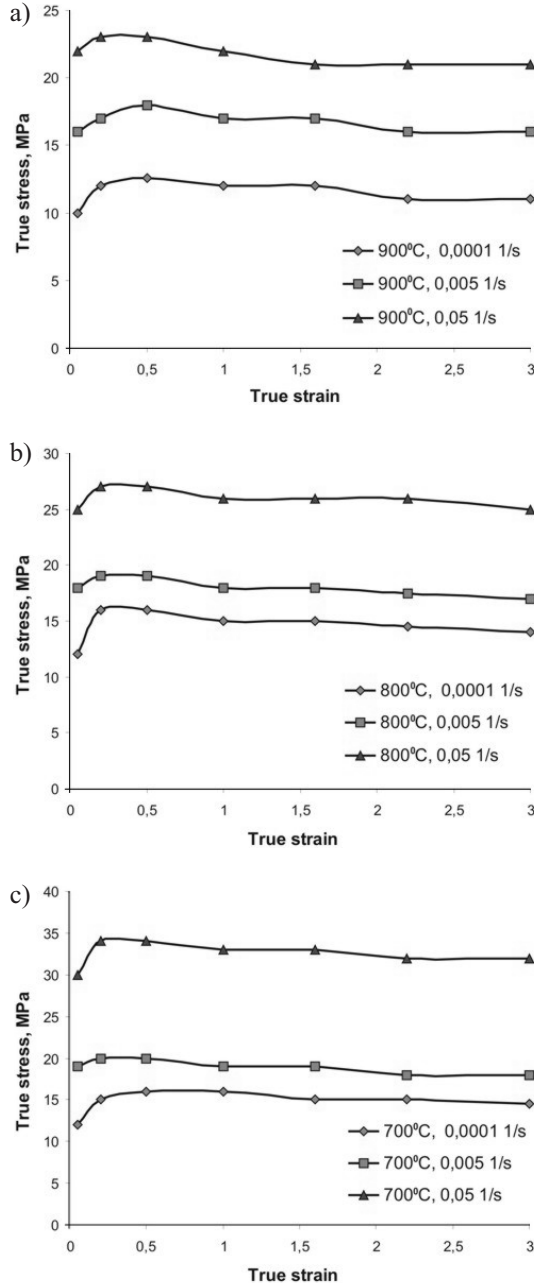


Fig. 3. Flow curves of the model alloy for temperatures: a) 900°C ; b) 800°C ; c) 700°C

The first of the analyzed alternatives corresponds to the typical industrial conditions, and the second – isothermal forging. The third alternative was forging at a ram velocity of 1 mm/s and tool temperature 800°C, whereas in the fourth case, process parameters typical of forming in superplastic conditions (ram velocity 0.001 mm/s and tool temperature 790°C) were assumed. To emphasize the effect of variables of the process conditions, the effect of temperature on the deformation can be neglected.

4. DISCUSSION OF THE RESULTS

In Figures 4, 5 and 6 there are maps of distribution of effective strain, effective strain rate and mean stress for relative height reduction of 45%. This value of reduction was selected as a most representative for the most characteristic distribution of strain of all analyzed cases.

The largest absolute values of effective strain are observed in forging at 500 mm/s in the area of transition from the volume of a hub into a cavity of a blade (Fig. 4a and 4b). Maximum effective strain observed is 2.0 for hot-die forging (Fig. 4b) and 2.2 for conventional tool temperature, 300°C (Fig. 4a). In forging in dies of temperature 790°C and a velocity of upper tool 0.001 mm/s there are two areas where high strain values, reaching 0.65 (Fig. 4d), are produced. The most uniform distribution of effective strain is observed in isothermal forging at a ram velocity 1 mm/s, with absolute value about 0.095 (Fig. 4c).

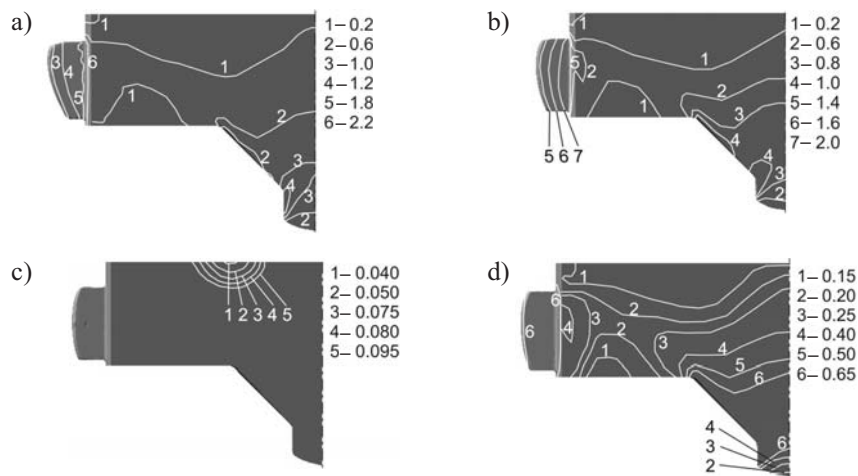


Fig. 4. Effective strain distribution for relative reduction 45% and following temperatures and strain rates: a) 300°C; 500 mm/s; b) 790°C, 500 mm/s; c) 800°C, 1 mm/s; d) 790°C, 0.001 mm/s

In all cases, the largest gradient of effective strain rate takes place in a transition area from the bulk into thin-walled section of a blade (Fig. 5e). Figures 5a through 5d show the maps of strain rate distribution in two areas of the detail shown in Figure 5e. As foreseen, the largest level of strain rate occurred in forging at higher forming speeds (Fig. 5a, 5b), whereas the least – at 0.001 mm/s (Fig. 5b).

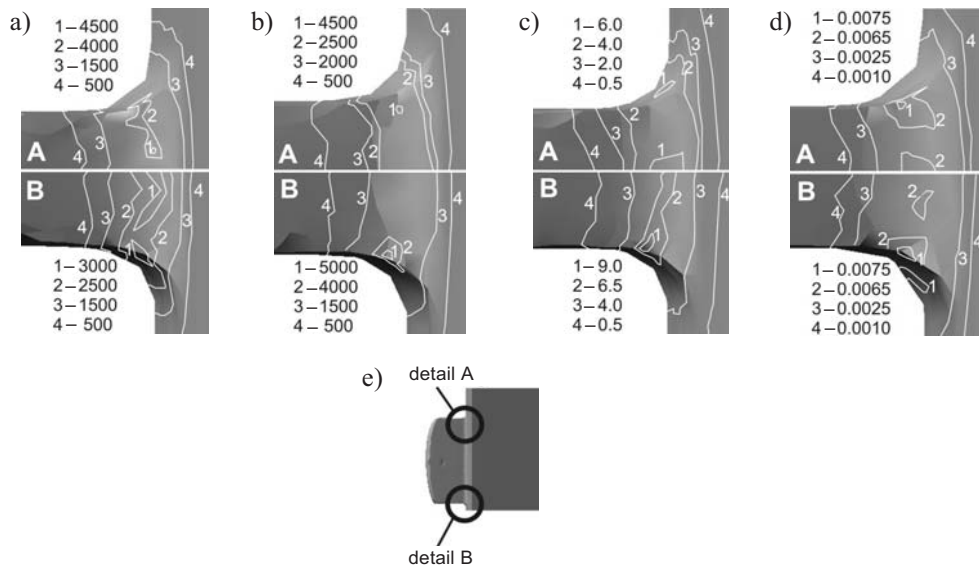


Fig. 5. Distribution of effective strain rate for relative reduction 45% and following temperatures and ram velocities: a) 300°C, 500 mm/s; b) 790°C, 500 mm/s; c) 800°C, 1 mm/s; d) 790°C, 0.001 mm/s, e) localization of detailed views

Mean stress distribution is quite similar in all analysed processes (Figs. 6a to 6d). Maximum values in individual processes are: 10 MPa at 1 mm/s and 0,001 mm/s (figs. 6c and 6d), 20 MPa at 300°C and ram velocity 500 mm/s (Fig. 6a), and 40 MPa for isothermal forging at 500 mm/s (Fig. 6b).

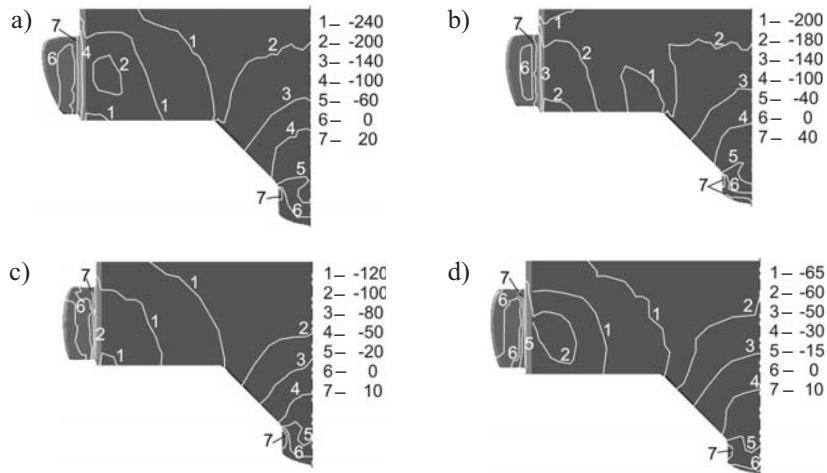


Fig. 6. Distribution of effective strain rate for relative reduction 45% and following tool temperatures and ram velocities: a) 300°C, 500 mm/s; b) 790°C, 500 mm/s; c) 800°C, 1 mm/s; d) 790°C, 0.001 mm/s

In Figure 7 a plotting of Load versus relative reduction for varying boundary conditions is shown. For higher speed forging processes the load values (curves 1 and 2 in Fig. 7) are respectively higher than those for lower speeds (curves 3 and 4 in Fig. 7). The loads observed at slow ram velocities go along with commonly observed levels superplastic forming. Moreover, on the strength of plots of load 1 and 2 in Figure 7 a rather insignificant influence of the tool temperature upon load during higher speed forging (0.5 m/s) can be concluded.

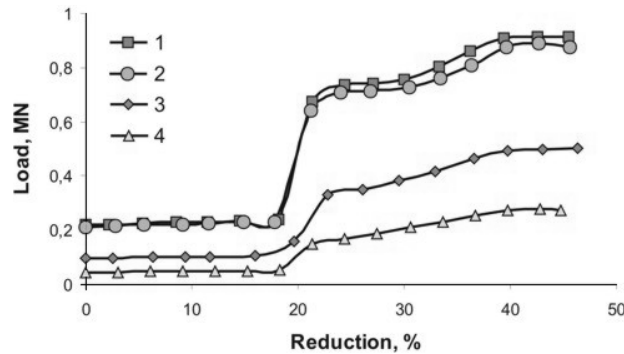


Fig. 7. Plots of load versus relative reduction in forging the impeller at following tool temperature and ram velocities: 1 – 300°C, 500 mm/s; 2 – 790°C, 500 mm/s; 3 – 800°C, 1 mm/s; 4 – 790°C, 0.001 mm/s

5. SUMMARY

Low speeds of forging, resulting in low strain rates, in forging a part of high complexity of shape, particularly, significant variation in sections, with a simultaneous use of heated dies are favourable for uniform distribution of effective strain. The best uniformity of effective strain was observed in forging processes in which superplastic conditions have been provided, which means, in addition to uniform temperature profile in the volume of the workpiece, also very low strain rate, reaching 0.001 mm/s.

Despite exceptionally complex configuration of the forged part and applied technology of extrusion in lateral directions, the value of extrusion load in four times lower if performed in superplastic conditions, and half lower if isothermal forged, that is at one thousand higher speed than in superplastic forming. This fact speaks for isothermal forging as an alternative forging process for complex-shape parts forged in high-melting alloys, which can be forged on low capacity presses, if uniform distribution of strain is not required.

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