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NUMERICAL INVESTIGATION OF PRODUCING A Ti6Al4V ALLOY JAW COUPLING SLEEVE-DISK BY ORBITAL FORGING

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The paper presents the results of a numerical analysis of the orbital forging process for producing a jaw coupling sleeve-disk. The analysis was performed using the programme Deform-3D, based on the Finite Element Method (FEM). It is assumed that a forging of the jaw coupling sleeve-disk is made of Ti6Al4V titanium alloy. A hollow preform is used as the billet. The hot orbital forging process is run using an industrial orbital forging press, MCOF 4000. The analysis focuses on the pattern of material flow, accuracy of the shape of the produced workpiece, as well as changes in the temperature of the material being formed.

Key words: titanium alloy, orbital forging, jaw coupling, hollow part, FEM

INTRODUCTION

Orbital forging is a technology mainly used for the cold (or hot) forming of flat, mainly solid parts. A detailed description of the technology is provided, among others, in the author's study [1], which offers a comprehensive analysis of the state of the art. Although there is a great deal of studies on orbital forging, few of them are devoted to the problem of forming hollow parts. For example, the research undertaken by Choi [2] or Guangchun [3] concerns only orbital forging for rings with a simple shape. Next, Sheu and Yu [4] carried out a research of cold orbital forging process for a simple ring gear part. In light of the above, the proposal of the present author to use the orbital forging process to produce a complex-shape hollow part under hot forming conditions is a new solution.

The main assumption of the new proposed technology is that a forging be produced from a specially prepared hollow preform. Such preform can be produced by machine forging (from solid billet), by rotary compression [5] or by rolling extrusion process [6]. In rotary compression, the desired shape can be obtained if tubes or sleeves are used as the billet [7]. Another assumption that the orbital forging process rests upon is that machining and technological allowances (e.g. web) need to be reduced. Unfortunately due to the characteristics of orbital forging [1, 8], some technological allowances cannot be entirely eliminated, only reduced to a considerable extent.

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GEOMETRICAL MODEL OF THE ORBITAL FORGING PROCESS

In order to investigate the orbital forging process for producing a jaw coupling sleeve-disk, a series of FEM-based numerical simulations were performed. The material model of the workpiece used in the simulations was Ti6Al4V alloy, its characteristics taken from the literature [9, 10]. It should however be noted that the numerical model of orbital forging have been put to successful experimental verification on numerous own publication, e.g. [1, 8].

The billet was a hollow preform (Figure 1a); for the purposes of the analysis, the preform was divided into about 90 000 tetragonal elements. The forging (Figure 1b) has a relatively long (as for orbitally forged parts) hub to which a sleeve-disk with a thickness of 9 mm is attached. On the sleeve-disk, there are six one-sided jaws, each 4 mm high. It is predicted that some internal flash with a thickness of 1 mm will be produced instead of the web. The reason for applying orbital forging to produce such part is that this process ensures obtaining a sleeve-disk with jaws whose shape and dimensions are the same as those of the final product.

The geometrical model of the process and the arrangement of tools are illustrated in Figure 2. The set of the lower tools consists of a lower die, a mandrel located in the center of the lower die, and a system of ejectors. These tools make a translational motion with a velocity *v*. Initially, the velocity *v* is maintained constant (in the FEM analysis two velocity values were applied: 15 and 20 mm/s); once the forming force F_{max} reaches the limit value, the velocity becomes variable. In this stage, the velocity *v* decreases in such manner that orbital forging can be effective at the constant forming force F_{max}. Two process variants were analyzed, i.e.

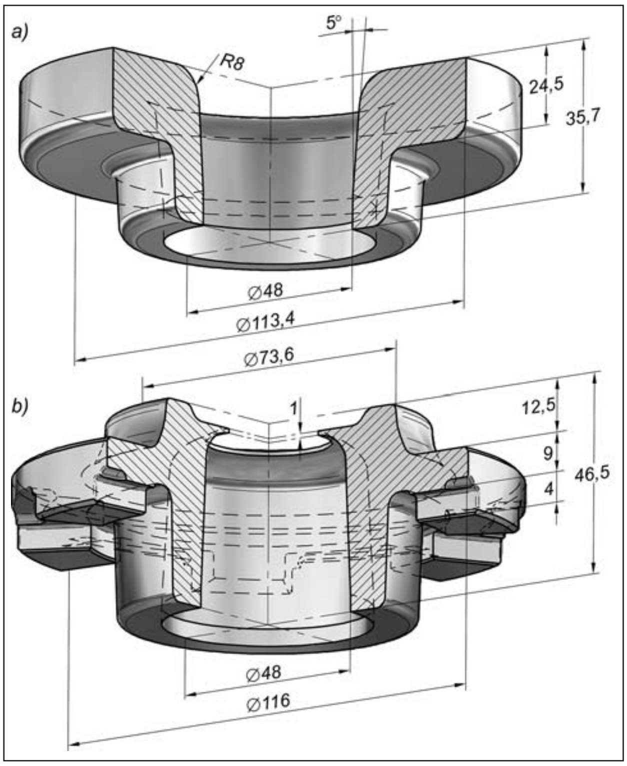

Figure 1 Shape of the investigated part: a) preform, b) hollow forging of a jaw coupling sleeve-disk

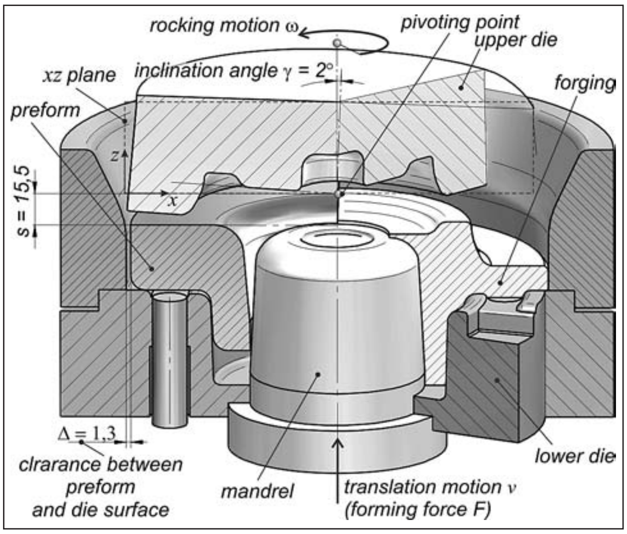

Figure 2 Design of the orbital forging process for producing a jaw coupling sleeve-disk

F_{max} is 4 000 kN and 3 000 kN. The final stage of orbital forging involves sizing the workpiece, which is done at the velocity v equal to zero. Such kinematic pattern can be performed using rotary forging presses, e.g. MCOF 4000 [11].

The upper die is inclined by the angle $\gamma = 2°$ ({xy} plain in Figure 2) and makes a rocking motion "round the circle" [1, 8] at the velocity $\omega = 300$ rpm; the velocity is maintained constant throughout the entire process. The pivoting point of the upper die is located at the distance s = of 15,5 mm from the butting face of the internal flash.

Other parameters applied in the FEM analysis are as follows: the initial temperature of the preform, T_w, is set to 950 °C, the tool temperature T_n is 300 °C, the friction factor m is 0,15 (the simulations are based on a constant friction model), the material-tool heat coefficient is set to 18 W/m^{2}K, while the material-environment heat exchange coefficient is 0,35 kW/m^{2}K.

NUMERICAL SIMULATION RESULTS OF THE ORBITAL FPRGING PROCESS

Figure 3 shows the typical distribution of effective strain in the orbital forging process for producing a jaw coupling sleeve-disk. The highest strain can be observed in the upper part of the workpiece and in the region of the disk. These regions are directly affected by the tools that perform a rocking motion. Also, it is observed that the lower part of the workpiece is deformed only to a small extent. This observation is confirmed by the flow net deformation, as can be seen in Figure 4.

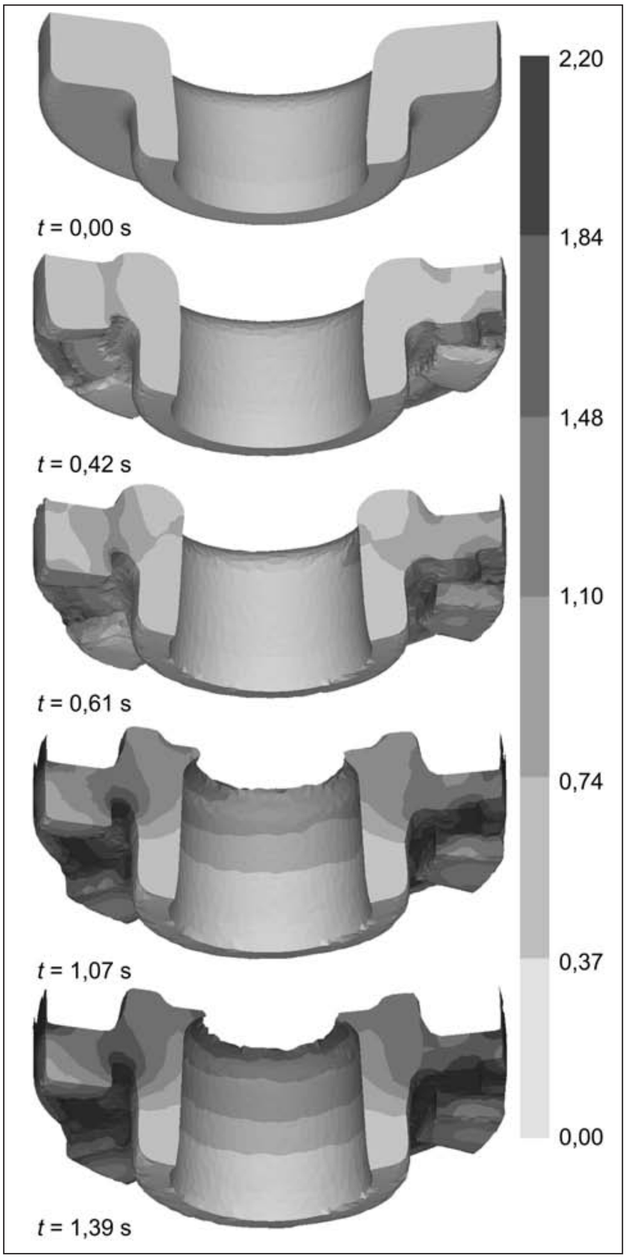

Figure 3 Workpiece shape changes and effective strain distribution when v = 15 mm/s and F = 4 000 kN

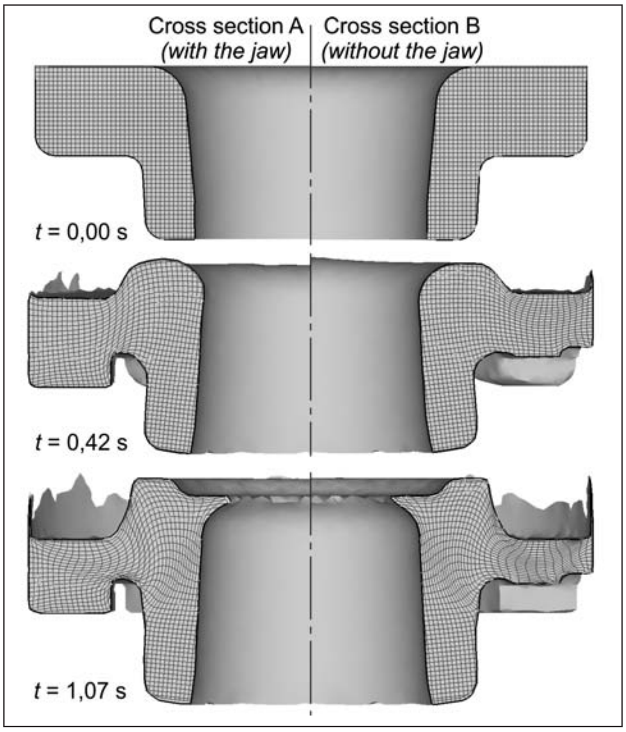

Figure 4 Flow net deformation in cross section of the workpiece, the same case as in Figure 3

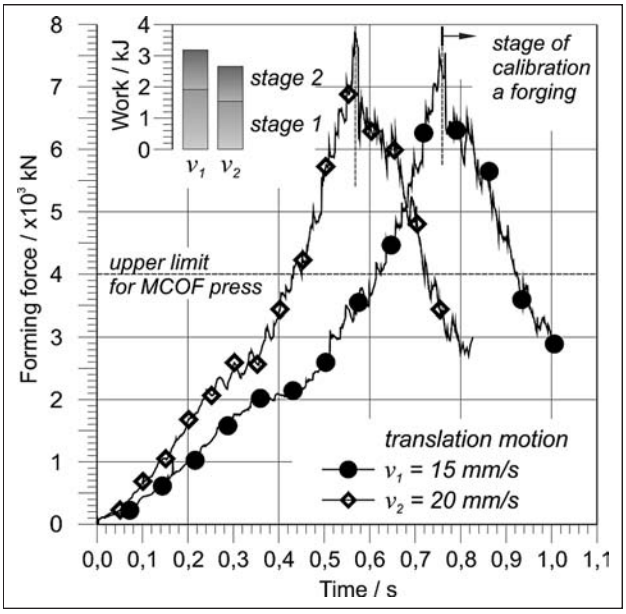

Figure 5 Forming force *F* versus time of the process and calculated work performed by the dies

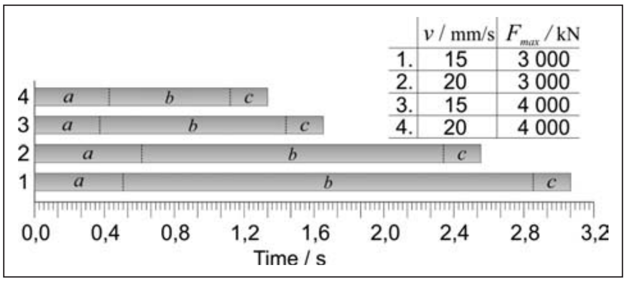

Figure 6 Duration of the orbital forging stages, depending on the velocity *v* and upper limit of the forming force F_{max}; description in the text

First, an almost fully shaped disk with jaws is produced. This part of the forging exhibits the most significant shape changes; producing jaws that have the desired profile poses no problems, either. The obtained flow net has a relatively favourable shape, which is desired. It can also be observed that changing the values of the examined process parameters (v, F_{max}) does not affect the shape of the flow net to any significant degree.

However, there is one undesirable phenomenon that occurs in the investigated process, namely-axial flash is produced on the edge. The phenomenon is unfortunately typical of orbital forging. This notwithstanding, the present author claims that the amount of this flash can be reduced if a value of the clearance Δ (Figure 2) is changed.

Figure 5 shows the distribution of the forming force F and the work performed by the dies. The chart illustrates the general effect of the velocity v on the conditions of orbital forging. The results were determined based on the assumption that the upper limit of the forming force F_{max} is not taken into account. In this case, it can be claimed that a change in the tool velocity v leads to a change in the maximum forming force F only to a small extent. A considerable change was observed, however, in energy consumption of the process, which results from the duration of the process.

Once the upper limit of the forming force F_{max} is added to the calculations, the distribution of the forming force F alters as one more stage can be observed during orbital forging. This stage occurs when the force F is for some time equal to the force F_{max}. This is schematically illustrated in Figure 6, where individual bars of the diagram stand for the duration of the following: a) forming at the constant velocity v of the tools when the force F increases, as shown in Figure 5, to the limit value of F_{max}; b) forming at the constant forming force F_{max}, and c) sizing the workpiece. The duration of the last stage is the same for all the analyzed cases.

Based on the obtained FEM analysis results, it is found that the velocity v and the upper limit of the force F_{max} have a significant effect on the orbital forging process taken as a whole. A decrease in the values of the two parameters leads to a longer time of the forming process. Comparing the results obtained at two different values of F_{max} (e.g. diagrams 1 and 3 in Figure 6), it is possible to introduce a parameter of minimum forming force at which the orbital forging process can be run at acceptable energy consumption. For the analyzed process, this minimum force amounts to about 3 000 kN, which is 37 - 41% of the total forming force obtained at the constant velocity v. The considerable elongation of the duration of the process carried out at F_{max} is caused by the fact that the velocity v decreases almost to zero.

The elongation of the duration of hot orbital forging is also vital in terms of thermal conditions. The longer material-tools contact causes that higher amounts of heat are transferred to these tools. This leads to a decrease in the temperature of the material and, in effect, lower plasticity of the material. What is more, this leads

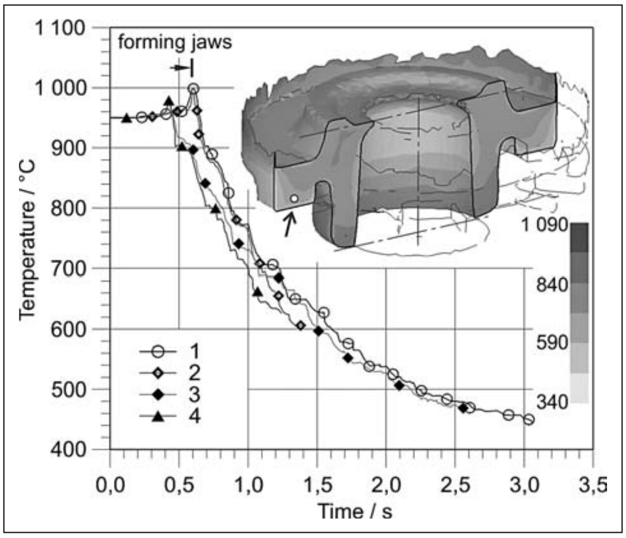

Figure 7 Temperature change versus time at a selected point in the workpiece; the meaning of the curves is given in Figure 6

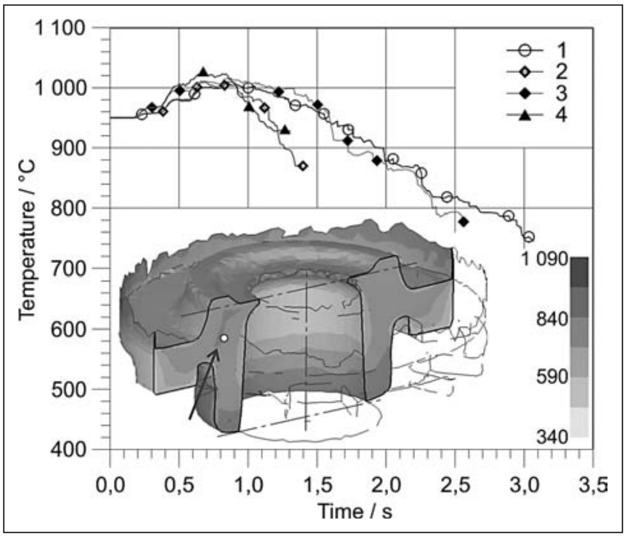

Figure 8 Temperature change versus time at a selected point in the workpiece; the meaning of the curves is given in Figure 6

to a higher temperature of the tools, too. Figure 7 shows the change in the material temperature in the region of the jaw, right at the surface layer. It reveals that the amount of heat transferred from the jaws to the tools is substantial. Even at the shortest duration of the process, the temperature of the material in the region decreases only to 600 °C.

Nonetheless, as long as the region of the material undergoes intensive deformation, the temperature is maintained high. This results from converting the deformation work to heat, as can be seen in Figure 8 that shows the history of temperature changes at one selected point in the workpiece. Comparing these results with those given in Figure 3, it is found that the temperature of the workpiece does not change in the regions where the material undergoes intensive deformation.

CONCLUSIONS

The orbital forging process for titanium alloy parts can be performed successfully if certain requirements are met. The most important of these requirements is that the process duration be as short as possible, which requires the use a forging press with a relatively high tool velocity and a relatively high pressure force. The analysis of the temperature history in the workpiece demonstrates that some zones of the tools need to be equipped with a cooling system. Such system could be mounted, for example, in the pass where jaws are formed. The analysis of the temperature history also reveals that as long as the material undergoes intensive deformation, the temperature remains at a level that ensures suitable plasticity of this material.

Analyzing the flow net deformation, it can be observed that that the forging produced has a favorable grain structure. There is, however, one drawback: the distribution of strain is not uniform, which means that the product must be subjected to heat treatment in order to normalize the structure of the material.

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Note: The professional translator for English language is M. Jung, Lublin, Poland