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FORMING A LEVER PREFORM MADE OF ALUMINIUM ALLOY 2014

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The paper presents the results of theoretical and experimental analyses of forge rolling for producing a lever preform made of aluminum alloy 2014. The forge rolling process was performed in an oval-circle rolling system. To verify the technological assumptions made, a comprehensive numerical analysis by finite element method was first performed, followed by experimental tests. The investigation demonstrated a high agreement between the numerical results and those obtained experimentally under real conditions. The numerical simulations allowed the determination of the distributions of strains, temperatures and normalized Cockcroft-Latham ductile fracture criterion.

Keywords: forge rolling, FEM, aluminium alloy 2014

INTRODUCTION

Elongated parts are most often produced by the die forging process using specially prepared semi-finished products, called preforms. An accurately designed and produced preform allows the minimization of forming forces as well as the reduction of material consumption and tool wear [1]. For this reason, preforms have to meet certain requirements: the shape of a preform should be as similar to the profile of a forging in the neutral plane as possible, while the areas of individual cross sections of the preform should be equal to the sum of relevant cross sections of a forging and flash. Preforms for forging processes can be produced by numerous methods, including open-die forging, die forging, cross-wedge rolling, longitudinal forge rolling, rotary forging and many more [2]. Longitudinal rolling is the optimal method for forming prefoms as it offers a number of benefits, such as high efficiency, the possibility of rolling and forging after single heating, high accuracy and repeatability of products, as well as the possibility of process mechanisation and automation. Selecting the technology for producing preforms mainly depends on the machine stock available, shape and dimensions of preforms and the specialization of a forging shop.

Forged products made of non-ferrous metal alloys are predominantly applied in the aircraft and aerospace industries. They are also very often used to produce various valves and hydraulic elements. Due to their properties, aluminium alloys are applied whenever low structural weight and high resistance to corrosion are required. Such materials are also characterized by a high strength to specific weight ratio, which is much higher than for steel [3]. Despite the numerous benefits they offer, light metal alloys (including magnesium and titanium alloys) are, however, relatively seldom used. This stems from their high cost as well as difficulties related to their forming and working. Nowadays aluminium is mainly processed by forging, rolling and extrusion methods (approx. 85 % of aluminium production). This results from the fact that wrought alloys exhibit better strength properties compared to cast aluminium alloys.

RESEARCH METHOD AND SCOPE

Nowadays 90 % of products manufactured by forging processes are made of steel. As a result, the guidelines for designing metal forming technologies are also based on experimental results for steel. In forging processes, the die impression accurately reflects the shape of a hot formed forging, irrespective of the material type used. Forge rolling technologies for preforms are difficult to develop due to a number of factors that need to be considered, inlcuding preform shape, location of characteristic sections on the length of a preform, acceptable deformation ratios, the number of rolling operations, and a rolling system to be adopted. All known methods for sizing rolls were developed for the purposes of rolling steel. What is more, none of these methods take into account all factors that affect the rolling process. As a result, every newly technological process needs to be put to experimental verification to correct possible defects. This study presents the experimental results of the forge rolling process for producing a lever preform made of aluminium alloy 2014. Figure 1 shows the shape and dimensions of this preform. The forging technology for producing a lever (for which a preform and a preform-forming technology were designed) from barstock is described in detail in the study [4]. However, due to considerable technological allowances resulting

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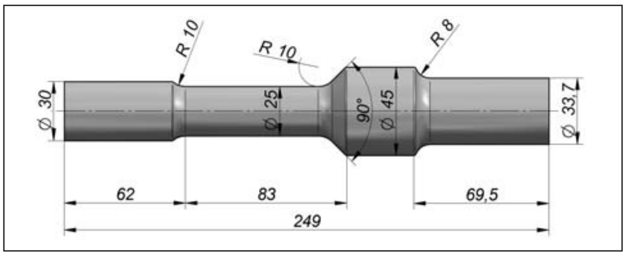


Figure 1 Shape and dimensions of a preform

from the shape of this semi-finished product, a new forging technology for producing a lever was developed, wherein longitudinally rolled preforms are used.

The choice of a rolling system is dictated by the shape and dimensions of a preform. The preform shown in Figure 1 was rolled using a circle – oval – circle system. The sizing of roll passes was developed based on the Bahtinov-Shtiernov method. The rolling of particular pivots was conducted at the following reductions of cross section: Z = 55,5 %; Z = 69 %; Z = 43,5 %. Reductions of cross section is defined as:

$$Z = (1 - (d / d_0)^2) \times 100\% \qquad (1)$$

where:

d – the pivot diameter after rolling in oval and circular impression,

d_o – the diameter before rolling.

Specific dimensions of the roll segments made according to this method are listed in Table 1. The forge rolling process for the investigated lever preform was conducted using a roll forging mill designed by the author of the paper. The mill and tools used in the experiments are illustrated in Figure 2. Basic technical specifications of the mill are listed in Table 2.

Table 1 **Dimensions of roll passes**

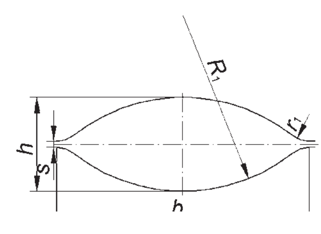
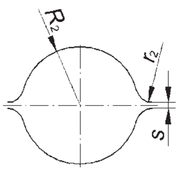
Pass No.							
	h	b	R_1	r_1	s	R_2	r_2
	mm						
1	29	76	55	7	3	16,85	4
2	24	62	45	7	3	15	4
3	20	42	24	5	3	12,5	2

Table 2 **Technical specifications of the roll forging mill**

Technical specifications of the roll forging mill	
Engine power / kW	22
Roll speed / rpm	28,1
Nominal torque per one roll / Nm	4 500
Roll range / mm	0 - 35
Roll diameter / mm	320
Roll width / mm	350
Length of external necks / mm	160
Weight / kg	4 500

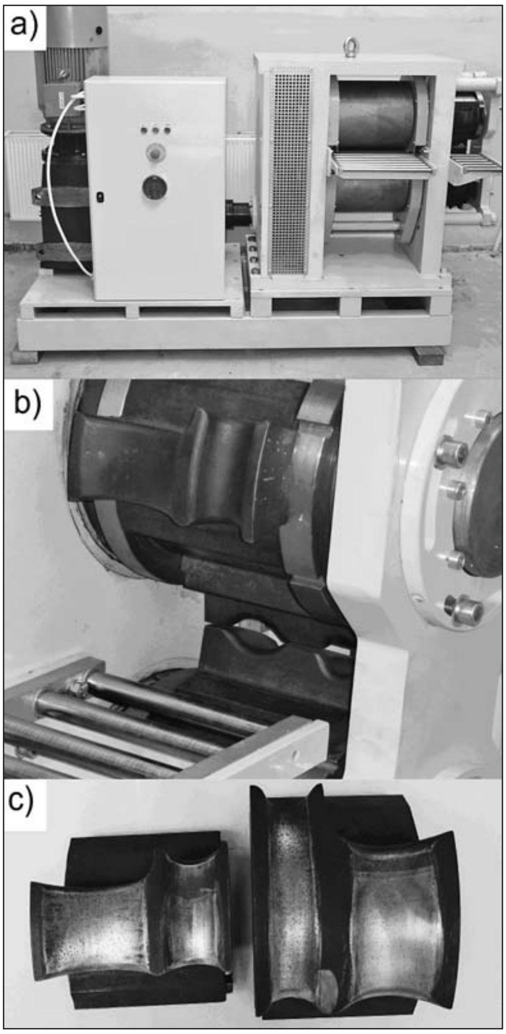


Figure 2 Roll forging mill - a),workspace –b), segments for rolling a preform –c)

A bar made of aluminium alloy 2014 was used as the billet; it had a diameter of 45 mm and a length of 132 mm. The diameter of the billet was selected such that the highest-diameter step of the preform would not be rolled. As a result, the number of operations and maximum values of deformation ratio on individual steps of the preform could be reduced. Prior to the rolling process, the billet was heated in an electric chamber furnace to a temperature of 460 °C. The rolling process was run without the use of lubricating agents. Also, the tools used in the experiments were not subjected to preheating.

EXPERIMENTAL RESULTS

The preforms obtained in the experiments are illustrated in Figure 3. Their dimensions compare well with those of the designed preform that is shown in Figure 1. It was observed in the experiments that preforms underwent bending in the region of the highest difference in diameters, which resulted from the difficulty in putting the billet in the impression in a correct position. Given the purpose of the semi-finished product, the bend does not disqualify this semi-finished product, as in a subsequent stage of the technological process, prior to forging, the preform is subjected to additional bending in the auxiliary impression [4]. No overlap or cracks were observed in the rolled preforms despite the fact that the process was conducted without tool preheating. The only shortcoming of this new rolling technology concerned the formation of flash along the axis of the preform between the roll segments when the end neck with a diameter of 30 mm was being rolled in the circular pass (Figure 4a). The amount of the flash was however insignificant and it was lapped in the oval pass during the rolling of the central step with a diameter of 25 mm. The rolled step of the preform was free from any lap and overlap that would impair the product quality. Prior to rolling, the billet was heated in the furnace and then held at the desired temperature for 20 minutes. It was observed that such heating method led to the formation of flash between the roll segments. In order to prevent overfill, the heating time was extended to 40 minutes. In effect, the produced forging was free from flash, as can be seen in Figure 4b. As a result of extending the billet heating time, defects on the frontal surface of the preform (that can lead to overlap during forging) were prevented, too.

NUMERICAL MODELLING

The numerical modelling of the multi-pass forge rolling process was conducted by the finite element method. The simulations were performed using Deform 3D software. The boundary conditions for the designed geometrical model of the investigated process were as follows: the billet-tool heat exchange coefficient was set to 15 kW/m^{2}K, while the billet-environment heat exchange coefficient was set to 0,2 kW/m^{2}K. The tool-material contact conditions were described by a constant friction model and defined by a friction factor set to m = 0,8. Flow curves of aluminium alloy 2014 used in the simulations are presented in Figure 5. Other parameters of the simulated process corresponded to the conditions under which the experiments were performed. Based on the numerical simulations, the distributions of strains, temperatures and fracture criterion were determined.

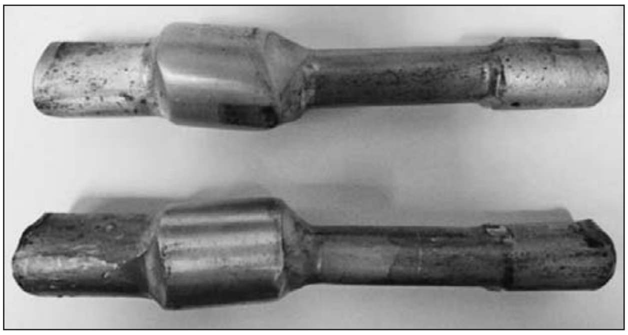


Figure 3 Preforms obtained in the experiments

Figure 4 End necks of preforms rolled after billet heating: a) 20 minutes, b) 40 minutes

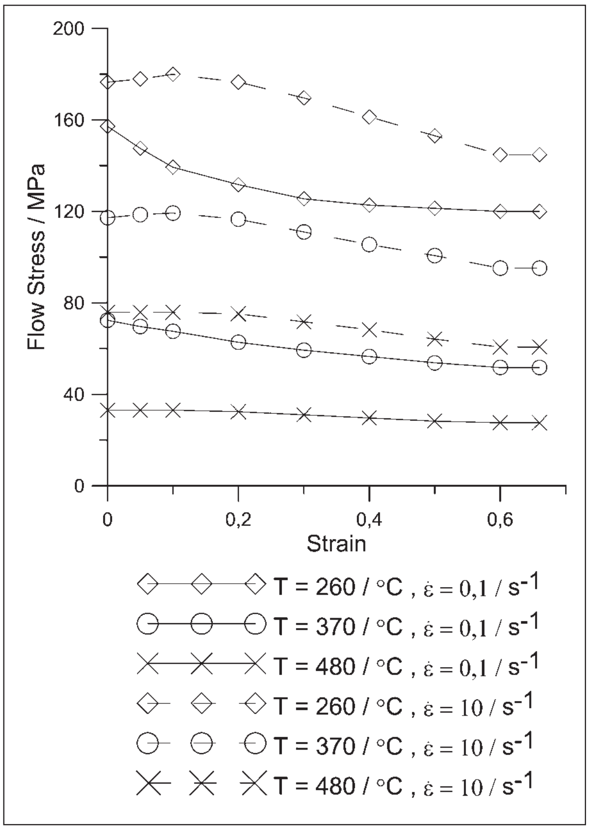


Figure 5 Flow curves of aluminium alloy 2014 used in the simulations

The distribution of strains in the axial section of a produced preform is shown in Figure 6b. The strains exhibit a substantial non-uniformity, which results from different deformation ratios applied to roll individual steps of the preform. The numerically simulated preform was deformed over its entire volume, excluding the step with the highest diameter that did not undergo rolling.

Temperature is one of the most significant technological parameters of metal forming, particularly when it comes to the forming of light metal alloys. The FEM-calculated temperature distribution in a finished pre-

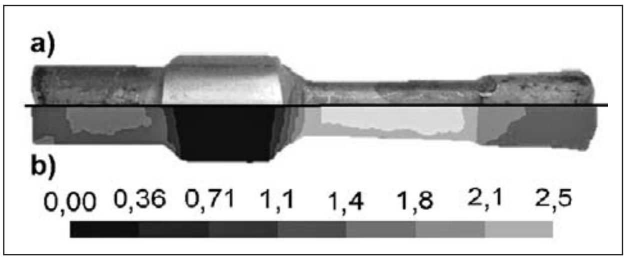


Figure 6 Shape of a preform obtained in the experiments – a), FEM-calculated shape and the distribution of effective strain - b)

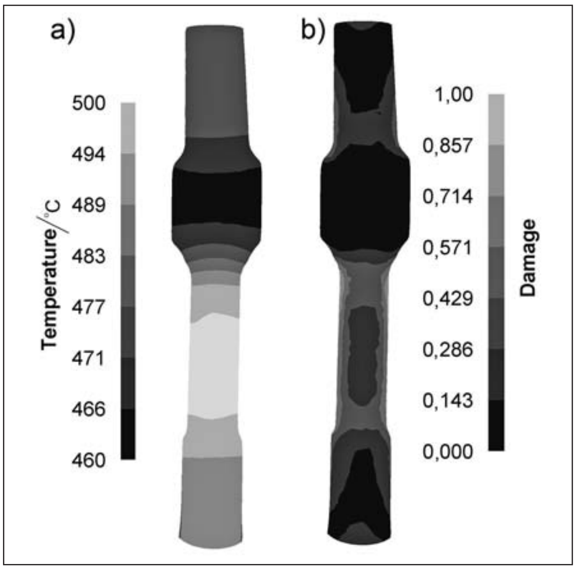


Figure 7 Numerically determined distributions of: a) temperatures, b) normalized Cockcroft-Latham fracture criterion in a finished preform

form is shown in Figure 7a. A relatively small temperature drop was observed in the non-deformed step of the preform, while the regions subjected to rolling exhibited an increase in temperature – in the lowest-diameter step of the preform the temperature amounted to 500 °C. According to the recommendations given, among others, in the study [5], forge rolling processes should be performed with tools preheated to a temperature ranging between 95 °C and 205 °C. Even though tool preheating was omitted in the present investigation, no intensive cooling of the material was observed. On the contrary – the temperature increased (exceeding the initial temperature value), which was caused by the deformation work and the action of friction forces.

Cracking is one of the main phenomena that limit metal forming processes for non-ferrous alloys. The ability to predict this undesired phenomenon already at the design stage allows for substantial time saving and reducing implementation costs. The FEM software that was used to perform the numerical simulations enables the prediction of material cracking based on various criteria. The criterion which is most often applied in metal forming is the empirical Cockcroft-Latham criterion defined by the dependence [6, 7]:

$$C = \int_0^{\varepsilon} \frac{\sigma_1}{\sigma_i} \, d\varepsilon , \qquad (2)$$

where:

σ_1 - the maximum principal stress,
σ_i - effective stresses,
ε - strain,
C - the value of the Cockcroft-Latham.

The integral calculated thereby is compared to the experimentally determined boundary value. The obtained distribution of the Cockcroft-Latham criterion in the axial section of a finished preform is shown in Figure 7b. The highest values are located between the preform steps with diameters of 45 mm and 25 mm. Relatively high values of the criterion C between individual preform steps suggest that the input radii of individual roll segments should be increased. Comparing the numerically calculated distribution of the criterion C with that obtained in the experimentally produced preforms, it can be concluded that aluminium alloy 2014 will not begin to crack even if the value of the criterion C is relatively high and amounts to 1.

CONCLUSIONS

Forge rolling is a widely used technology for producing steel preforms and forgings. Nonetheless, this method is relatively seldom applied to produce semi-finished products made of non-ferrous metal alloys. This mainly stems from difficulties in developing a technology for forming these materials due to a narrow range of temperatures for hot working, cracking and excessive grain growth.

The research results have demonstrated that light metal alloys can be formed by rolling using forging impressions. Furthermore, the suitability of using the proposed impression design (commonly used for steel forgings) has been confirmed. Apart from the correct shape of forging impressions, it is vital that suitable thermal conditions be ensured in forge rolling processes. The experimental and theoretical results have confirmed that the preheating of tools is not necessary. This predominantly results from a short material-tool contact and the conversion of friction forces works into heat, which compensates for the losses of heat that is carried away to the tools and environment. The results obtained allow the speculation that forge rolling processes can be used to form other groups of materials, such as magnesium and titanium alloys, which could result in reduced consumption of these alloys.

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