Numerical analysis of a skew rolling process for producing a crankshaft preform

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Research Article

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Abstract: The paper describes a new method for forming a crankshaft preform. The method is based on the skew rolling technique. With this method the part is formed by three tapered rolls rotated with the same velocity and in the same direction. Simultaneously, the rolls either converge or diverge depending on the desired cross section of the product. The numerical modeling enabled determination of the distributions of effective strains, temperatures, and damage function according to the Cockroft - Latham criterion, as well as variations in the loads and torques during rolling. The results confirm that a crankshaft preform can be formed by the proposed skew rolling method.

Keywords: crankshaft, FEM, preform, skew rolling

1 Introduction

Crankshafts are manufactured by means of casting, waste machining, die forging or using TR devices. In die forging, preforms are formed from solid bars. Given the necessity of process optimization in terms of material yield, attempts were made to prepare preforms for die forming by preliminary forming of billet. Such attempts were made by German researchers with respect to cross wedge rolling [1, 2]. They found that the cross wedge rolling technique offers a number of advantages such as high efficiency, a better use of material, reduced energy consumption as well as the possibility of process automation. Despite these advantages however, the forming of a two-cylinder crankshaft preform is characterized by high rolling forces (they even reach 100 kN at the tool velocity set to 300 mm/s). In addition, it requires the use of large-size flat-wedge tools - even with a length of 3.9 m. Hence, this rolling process requires the construction of large-size and energy consuming machines, which makes the process less cost - effective.

In light of the above, a new method for forming large preforms by skew rolling is proposed, its schematic design shown in Fig. 1 [3–7]. The method consists in forming a part by three tapered rolls which are located on the workpiece circumference at every 120°. The rolls are mounted askew to the workpiece axis, at an angle θ, and they are rotated with the same velocity in the same direction.

Moreover, the rolls can converge and diverge in order to reduce the cross section of the billet. Their spacing is synchronized with the axially moving holder, in which the end of the workpiece is mounted. Owing to advances in automatic control engineering, the motion of these tools can today be controlled numerically. It should be highlighted that the same rolls can be used to form various parts, the end shape of which will result from the way in which they are programmed. Due to the universality of the forming tools and the change in their feed rate, the proposed skew rolling technique is cost - effective even with respect to piece production.
This paper reports the results of a numerical analysis of a forming process for producing a preform of two-cylinder crankshaft by skew rolling. The analysis was performed by the finite element method on a model of a rigid-plastic material without the spring back effect. The aim of the numerical analysis, the results of which are reported in subsequent sections of the paper, was to find ways of reducing material and energy costs in preparation of forgings by die forging.

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The numerically analyzed crankshaft preform is shown in Fig. 2.

Each of the four heads of the 75 mm diameter preform is for a single arm of the shaft double crank. The next diameter, 48 mm, is for the main pin, crank pins and flanges for mounting the crank shaft. On the other hand, the steps with the diameters: 48 mm, 41 mm and 31 mm, are used for wheels timing gear and, possibly, auxiliary drives.

Figure 3 shows a numerical model of the skew rolling process for producing a crankshaft preform using three tappered rolls (each described by a diameter of 180 mm and the angle $\alpha$ of 25°) and a billet with an external diameter of 75 mm and a length of 305 mm.

In the present analysis the side surface of the workpiece is fixed, thus the holder is omitted. The translational motion of the holder is replaced by axial feed of the rolls, which enabled performing the numerical simulation without any changes in the kinematics of the process. It was assumed that during forming the rolls would be rotated in the same direction with the same rotary velocity set to 60 revolutions per minute. In order to obtain the desired shape of the product, we determined the motion sequence of the rolls as well as their axial and radial velocity of feed.

The variations in the axial and radial feed velocities are shown in Fig. 4.

The dimensions of the forming roll used in the skew rolling process for producing a crankshaft preform are shown in Fig. 5.

The billet was made of a rigid-plastic material and assigned the properties of C45 steel. The spring back effect was not taken into account. The model of the material was described by the equation:

$$\sigma_p = c_1 \cdot e^{(c_2 \cdot T)} \cdot \phi^{(n_1 \cdot T + n_2)} \cdot e^{(l_1 \cdot T)} \cdot \dot{\phi}^{(m_1 \cdot T + m_2)}$$

Equation (1)

where: $\sigma_p$ is the yield stress [MPa], $\phi$ is the strain intensity, $\dot{\phi}$ is the strain rate [1/s], $T$ is the temperature [°C].

Other parameters in the calculations were as follows: the friction factor on the tool-material contact surface was set to 0.95; the heat exchange coefficient between the rolls and material was fixed at 10000 W/m²K; the billet temperature was set to 1180 °C while the temperature of the tools was made equal to 100 °C. The final form of the equation was:

$$\sigma_p = 2859.85 \cdot e^{(-0.00312548 \cdot T)} \cdot \phi^{(0.0000044662 \cdot T - 0.101268)} \cdot e^{(-0.0000727561 \cdot T - 0.0081808)} \cdot \dot{\phi}^{(0.000151515 \cdot T - 0.00274856)}$$

Equation (2)

The numerical model was designed using the finite element method - based simulation software Simufact Forming v.12. The element size and remeshing parameters were
set arbitrarily by the authors of this paper such that it was possible to reach a compromise between computational accuracy and computation time.

3 Numerical results

The numerical results demonstrate that two-cylinder crankshaft preforms can be produced by skew rolling with three tapered rolls.

The results are shown in Fig. 3b. Individual steps of the worked out part were stepped one after another. At the product edges allowance was left, where one of them is needed to billet fixing (place for the holder), yet, the second one is destined for rolls coasting. In the further material machining they have to be removed, e.g. by cutting. It is, of course, possible to optimize the mentioned above allowance by reducing billet material length in order to avoid large waste amount. It is important that although the diameter of the worked out product is small in relation to its length, it does not undergo bending. It is caused by axial impact of tensile stresses present at the semi-finished part area between the rolls and the holder.

Figure 6 shows the distribution of the strains on the surface and in the axial section of the crankshaft preform.

The analyzed distribution shows that higher strains are present near the surface, while smaller ones are located in the product axis. This is caused by the friction force acting between the tools (rolls) and the workpiece. It was also observed that the strains increase with increasing the cross sectional reduction of the billet. Such a distribution is typical for the skew rolling process.

In compliance with the assumptions, the rolling operation lasted 29 seconds, which is a considerably long forming time. During the process however, the contact between the tools and the workpiece is local, so the temperature of the workpiece does not decrease significantly. This is confirmed by the distribution of the temperature in the produced part, as shown in Fig. 7.

Figure 7: Distribution of the temperature (in °C) in the preform produced by skew rolling.

It should be highlighted that the loss of heat carried away to the tools and environment is compensated for by the heat generated by friction work during the forming process.

The distribution of the damage function calculated according to the Cockcroft - Latham criterion illustrated in Fig. 8 is connected with a change in the effective strain.

The increase in cross sectional reduction causes an increase in the damage function. At the same time, material cracking is most likely to occur in the region of the highest reduction in the diameter of the workpiece.

Variations in the loads in the skew rolling process are shown in Fig. 9. As can be observed, the changes in the
values of the loads acting on the roll (both axial and radial) depend on the changes in the workpiece diameter.

The increase in cross sectional reduction of the workpiece causes an increase in loads. The radial load increases to 77 kN, while the axial load is 17 kN. Maximal forces acting on the holder are equal triple value of the axial force acting on the roll. Therefore, the obtained parameters confirm the possibility of building a mill of light construction with the application of power system of power lower than in the case of cross-wedge rolling mills.

Similar dependencies can be observed regarding the variations in the torque on the roll, as shown in Fig. 10.

The torque on the roll depends on the changes in the workpiece diameter. Its maximal value during the analyzed rolling process was 1650 Nm. The variations in the torque during the forming process are similar to those in the loads which are illustrated in Fig. 9.

4 Conclusions

Based on the results of the conducted numerical analysis, the following conclusions have been drawn:

- the skew rolling method can be used to produce a two-cylinder crankshaft preform,
- the process is highly universal, as it enables forming a number of parts of various shapes using one set of rolls,
- strains are superficial (they are higher on the surface of the produced part than in its axis),
- despite the long forming time, the billet temperature does not drop below the recommended hot working temperature,
- compared to the size of parts being formed, the torque and loads in skew rolling are low,
- research on skew rolling processes for forming products of varying shapes should be continued and its scope should be extended to include experimental tests.

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