APPLICATION OF COMPUTER SIMULATION TO A PROBLEM OF BEARING INDUSTRIAL WASTE RECYCLING

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Abstract
Within this work the modification of bearing rings manufacture technology was analyzed and modified in order to increase the material utilization. A common technology of bearing production which has been using in the Kursk metallurgical plant was analyzed by means of computer aided mathematical simulation. The mathematical model of the metal flow during hat forging was developed and implemented in own finite element based software which calls SPLEN. Construction of end-to-end solution algorithm based on common approach and on use of SPLEN software complex basic computation systems is also considered. With the help of developed simulation model the high-performance technology of the production of bearing rings from disk-shape scrap manufacturing application was proposed verified and implemented in the Kursk bearing plant. The problem of the comprehensive use of the disk-shaped rejects after the forging of tower-shaped forging of bearing rings was solved using the computer simulation in developed software. The final form of a bearing ring blank depends on the geometry characteristics of initial flat ring and the punch die. This characteristics were described mathematically by a values which were and varied in order to achieve a best form of the tower-ring and avoid the formation of defects. According to the accomplished calculations, the working surface of the punch providing for the best final configuration of the spreaded ring was designed which allows to increase the metal utilization factor up to 75% - 85%. Comprehensive technology for the use of hot-rolled bar in the process of bearing rings forging was developed. All of considered technologies and methods are covered by patent and effectively used in industrial conditions.

Keywords:
Waste recycling, industrial bearing, computer simulation, metal saving.

1. INTRODUCTION

The basic goal when designing technological processes of metal forming, is a choice of equipment, tools, operations and manufacture conditions. The technology shod be designed and realized in compliance with the optimal thermomechanical conditions of forming process to achieve the required geometrical strength and quality characteristics of the product. It should also consume minimal resources to produce a high-quality semi-finished parts or a product with a necessary level of physical, chemical, mechanical and other properties according to the preset specifications. The preconditions of an effective implementation of an acceptable solution providing for viability and competitiveness, are prepared at the design stage of a new technology or when upgrading a technology of metal forming [1]. The application of a mathematical and computer simulation commonly based of finite element method (FEM) at the design stage of a technology become at recent years a usual practice.

Engineering calculations of the strength for the elements tools, parts and units, of rigidity for structures of general and special purpose, and of stability of forms at critical loadings in elastic and plastic-and-elastic areas provide for a possibility to optimize the size, form, mass and properties. In particular, this is provided from the point of view of metal saving or material replacement for their manufacturing or arrangement of conditions for an increase in efficiency and reliability.
Within this work the modification of bearing rings manufacture technology was analyzed and modified in order to increase the material utilization. For the computer simulation and analysis of this technology was used own FEM based software which calls SPLEN. This software is able to predict geometrical evolution of the simulated specimen in condition of hot deformation, determine the stress-strain conditions as well as temperature distribution in the volume of deformed material. It was mathematically and experimentally verified and applied for solution of simulation and optimization tasks in many fields of metal forming industry [2-5].

2. MATHEMATICAL MODEL

The spatial mathematical model of hot deformation bases on the rigid-viscoplastic formulation of an axisymmetric task with an equilibrium equations given as follows:

\[
\begin{align*}
\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\sigma_x - \sigma_y}{x} &= 0, \\
\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \tau_{xy}/x &= 0.
\end{align*}
\]

(1)

where \(\sigma_x, \sigma_y, \sigma_\varphi\) and \(\tau_{xy}\) are the components of stress tensor which related to the components of strainrate tensor \(\varepsilon_x, \varepsilon_y, \dot{\varepsilon}_\varphi\) and \(\dot{\gamma}_{xy}\) as follows:

\[
\begin{align*}
\sigma_x &= 2\mu \varepsilon_x + \left( K\Delta t - \frac{2}{3} \mu \right) \dot{\varepsilon}_x + \sigma^*, \\
\sigma_y &= 2\mu \varepsilon_y + \left( K\Delta t - \frac{2}{3} \mu \right) \dot{\varepsilon}_y + \sigma^*, \\
\sigma_\varphi &= 2\mu \varepsilon_\varphi + \left( K\Delta t - \frac{2}{3} \mu \right) \dot{\varepsilon}_\varphi + \sigma^*, \\
\tau_{xy} &= \mu \dot{\gamma}_{xy}, \quad \tau_{yx} = \tau_{xy} = 0.
\end{align*}
\]

(2)

Here \(\Delta t\) is the time step of the solution, \(\mu\) is nonlinear viscosity coefficient determined from plastometric experiments [6-7]. It is a function of effective strain rate and is parametrically depends on effective strain and temperature \(\epsilon_e, \varepsilon_0, T\). The material is assumed to be compressible with the hydrostatic compression coefficient \(K\). The compression rate \(\dot{\varepsilon}\) and accumulated hydrostatic pressure are given as:

\[
\dot{\varepsilon} = \varepsilon_x + \dot{\varepsilon}_x + \dot{\varepsilon}_\varphi
\]

(3)

\[
\sigma^* = K \int_0^{t-\Delta t} \dot{\varepsilon} \, dt
\]

(4)

On the part of boundary contour which interact with the die, the boundary conditions of contact type [5, 8] are accepted. The friction low is given by Levanov's formula [9]:

\[
\tau = k_{fr} 0.58 \sigma_0^\delta \left( 1 - \exp \left( -1.25 \frac{|P|}{\sigma_0^\delta} \right) \right)
\]

(5)

where \(|P|\) is a normal pressure; \(k_{fr}\), is generalized characteristic of the contact surface (friction factor); \(\sigma_0^\delta\) is an effective stresses taken in the contact layer.

This complex task, being a physically and geometrically nonlinear integral-differential problem with boundary conditions in stresses, travel speeds and of a mixed contact type (2), preset on changing with time and
unknown boundary, is solved using up-to-date personal computers by means of the finite elements method [10, 11]. Linearization of the problem is implemented using the method of A. A. Ilyushin [12], which convergence has been proved [13].

3. THE TECHNOLOGY OF BEARING RINGS MANUFACTURE

The technology in question have been using at the automated line L-309 of Kursk Bearing Plant for production of bearing rings. The basic steps of this technology are presented in Fig. 1. After a hot-rolled bar cutting a so-called “tower” piece produces by three forging operations. Afterwards the forged semiprodct parting in three pieces: two bearing rings (external and internal one) and waste disk.

![Fig. 1 A technological chain of bearing rings forging from a hot-rolled rod](image)

The forging operations was simulated at the developed software in order to estimate the temperature and stress-strain conditions of the process. The results of simulation are shown at Fig. 2 which represents the finite element mesh and distribution of the effective strain in a different stages of forging. The results of simulation were used for analysis and optimization of forging operations. Changing of the intermediate die form allows to makes the effective strain distribution more uniform and decrease maximum power of forging operations which should rise up the durability of the equipment.

Formerly, disk and trailer waste were considered to be scrap metal and were melted for further recycling. In this case the metal utilization factor which gives as a ratio of product weight to the weight of the initial semiproduct was equal to 60% - 70%. The aim of further investigation was to increase this value by using the waste disk as an initial semiproduct for another bearing ring. Towards this end the new technology of waste disks recycling was proposed. Its base steps are shown at Fig. 3. After the upsetting the flat ring is cutting out which at the next operation is everted to the tower-ring.
General advantages of the described technology are obvious. Basic difficulties of its implementation are mainly connected with one operation only – the operation of forging with the spread of a flat ring into a tower-ring. If the blank size and the die tools geometry are chosen improperly, the forging with the spread results either in an irremovable spoilage, which appears as big internal shrinkage cavities in the top part of the ring and even as cut of a part of the metal, or appears as a high fin which working demands an additional operation complicating and appreciably slowing down the bearing rings production process. In the latter case, high fins are often accompanied by an inadmissible shrinkage of the bottom part of the ring.

Solving these problems by means of experimental selection is extremely inconvenient, and as practice has shown, this expensive process may not give positive results. A reasonable alternative is a computer simulation with a subsequent computer-aided implementation.

The process of bearing ring forging from a flat ring obtained by waste disk parting was simulated and analyzed by means of SPLEN software. The results of simulation are presented in Fig. 4. The final form of a bearing ring blank depends on the geometry characteristics of initial flat ring and the punch die. This characteristics were described mathematically by a values which were and varied in order to achieve a best form of the tower-ring and avoid the formation of defects. According to the accomplished calculations, the working surface of the punch providing for the best final configuration of the spreaded ring was designed which allows to increase the metal utilization factor up to 75% - 85%.
The results of a test forging and the subsequent commercial operation showed the full conformity of the forecasts on the metal form changing accomplished with a computer using the SPLEN software, with a real form changing of the rings [14]. The average forecast error of geometrical size when forging an experimental batch of 300 bearing rings did not exceed 2 per cent.

The technology for processing of wastes was implemented at the Kursk bearing plant, and the methods of its development are protected by a patent. The photographs of semi-products which uses in the process of waste disks recycling and final machined bearing ring obtained by developed technology are presented at Fig. 5.

4. CONCLUSIONS

The new technology of bearing production waste recycling was developed and analyzed. It was shown that a waste disks which usually appears as a side product during the conventional bearing production can be used for feather production without its re-melting.
The application of SPLEN computer software in a stage of mathematical simulation of the forging operations allows to analyze the thermomechanical stress-strain and power characteristics of the technology procedures. Changing of the intermediate die form allows to make the effective strain distribution more uniform and decrease maximum power of forging operations which should rise up the durability of the equipment.

The optimal geometrical characteristics of the punch die and waste ring were found to achieve a best form of the tower-ring and avoid the formation of defects. The metal utilization factor was increased up to 75% - 85%.

All developed technologies was implemented at the Kursk bearing plant, and protected by a patent.

LITERATURE