INFLUENCE OF MAIN PARAMETERS OF FORGING PROCESS AND OPTIMAL CHOICE OF SHAPE ANVILS ON THE INTERNAL QUALITY OF FORGING FOR STEEL WCL

Grzegorz Banaszek,
Henryk Dyja,
Sebastian Mróz,
Szymon Berski

TECHNICAL UNIVERSITY OF CZĘSTOCHOWA Faculty of Metallurgy and Materials Engineering, Al. Armii Krajowej 19, 42-200 Częstochowa, PL

Abstract
In this work the influence of main parameters of forging process and shape of tools on the homogenisation of local strain values in whole cross section of the forging was discussed. The theoretical analysis of the researches was verified in the laboratory tests. The values of the main technological parameters of forging process was stated. Optimal assembly of anvils for free forging was proposed.

1. INTRODUCTION
Studies on uniforming the distribution of strain intensities on the cross-section of forgings are reported in several works [1,3,9]. These indicate that uniforming of the distribution of strain intensities in forgings is affected significantly by the main process parameters, such as draft, feed, temperature and the shape and dimensions of anvils. The above studies aimed at the optimization of forging process parameters and the shape of anvils to obtain forgings free from internal defects.

In the present work, the studies were directed towards determining the shape and geometry of tools to obtain a uniform distribution of strain intensities in the forgings during the forging process.

Theoretical studies were carried out for the triaxial state of deformation, and their results were verified in laboratory conditions.

2. MATERIALS USED IN INVESTIGATIONS AND THE BOUNDARY CONDITIONS OF THE FORGING PROCESS
Theoretical studies and laboratory tests were carried out for specimens with a diameter and a height of 80 mm made of WCL alloy steel designed for hot operation with a chemical composition as shown in Table 1.

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Chromium %</th>
<th>Phosphorus %</th>
<th>Cobalt %</th>
<th>Silicon %</th>
<th>Manganese %</th>
<th>Copper %</th>
<th>Molybdenum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCL</td>
<td>4.5±5.5</td>
<td>&lt;=0.03</td>
<td>&lt;=0.3</td>
<td>0.8±1.2</td>
<td>0.2±0.5</td>
<td>&lt;=0.3</td>
<td>1.2±1.5</td>
</tr>
</tbody>
</table>

The laboratory tests and experimental examinations of a model ingot with a diameter and a height of 80 mm were performed in forcing-through radial shaped dies shown in Figure 1.
The draft during forging in shaped dies was 20%. After the first upsetting, the forging was tilted by 90°. The feed rate was 0.75 m/s. The initial temperature of the stock material was assumed to be constant within the whole volume, being at 1150°C [4]; the temperature of the anvils was assumed at 350°C, while the ambient temperature at 30°C [4]. The properties of the steel was taken from the database of the FORGE2 software (for the temperature range 750–1250°C).

3. THEORETICAL ANALYSIS OF THE FORGING PROCESS

For the analysis of the forging process, FORGE3, a commercial program developed at CEMEF, Ecole des Mines de Paris, was used. The FORGE3 program relies on the finite-element method. It enables the thermomechanical simulation of the processes of plastic working of metals in the axial-symmetrical and the flat states of deformation. The calculations of the metal flow pattern, and stress fields, deformation velocity, strains and temperature are carried out under the assumption of a visco-plastic model of the deformed body based on a six-node grid of triangular elements. This solution is described in numerous publications by Prof. Chenot’s team. In the model discussed, the behaviour of the material deformed is described by the Norton-Hoff law:

$$ S = \frac{2K}{(3\varepsilon_i)^{m-1}} \dot{\varepsilon} $$  \hspace{1cm} (1)

where: $s$ – stress deviator tensor, $\dot{\varepsilon}_i$ – deformation rate intensity, $\dot{\varepsilon}$ - deformation rate tensor, $K$, $m$ – material constant.

The law of friction on the metal-tool contact surface is given by the following equation:

$$ \tau = \alpha * K|\Delta v|^{p-1} * \Delta v $$  \hspace{1cm} (2)

where: $\tau$ - unit vector of friction forces, $\alpha$ - coefficient dependent on the contact surface condition, $\Delta v$ - velocity of slip of the material relative to the tool, $p$ – parameter dependent on temperature

As a consequence, the actual velocity field is calculated from the condition for the minimum of the functional:

$$ J = v \int K_\nu \left( \sqrt{3\varepsilon_i} \right)^{m+1} * dV + \int \frac{\alpha K_\nu |\Delta v|^{p+1} * dS + \rho_p \int K(\varepsilon_{ij}) \dot{\varepsilon}_{ij} * dV}{2} $$  \hspace{1cm} (3)

where: $K$, $m$, $\rho_p$ – material constants dependent on temperature, $\rho_p$ – penalty function.

The thermal part of the model utilizes the solution of the diffusion equation in the form of:
\[- k \frac{\partial T}{\partial n} = h \varepsilon r \left(T - T_0\right) + \varepsilon r \sigma \left(T^4 - T_0^4\right) \tag{4}\]

where: \(n\) – unit vector normal to the surface, \(T_0\) – ambient or tool temperature, \(\varepsilon r\) – surface emissivity, \(\sigma\) – Boltzmann constant, \(h\) – heat exchange coefficient.

As a result of the computer simulation of the forging process, a significant uniforming of local forging ratios were found in the whole volume of the forging and on its cross-section. Upon upsetting the material in radial-trapezoid anvils in the first operation values of local deformations in the range 0.98\(\pm\)0.85 were obtained in the central parts of specimen cross-sections, while in the range 0.76\(\pm\)0.66 in the external specimen layers (Fig. 2).

**Fig. 2.** Distribution of strain intensities after the first upsetting in shaped dies: A1, A2, A3 – cross-sections in the locations of conical convexities that had been made in the anvils; B – top view.

**Fig. 3.** Distribution of strain intensities after the second upsetting in shaped dies (tilted by 90°): A1, A2, A3 – cross-sections in the locations of conical convexities that had been made in the anvils; B – top view.
4. VERIFICATION OF THEORETICAL STUDIES

For the verification of the theoretical studies, φ80x50 mm specimens were used, on which 5x5 mm-square coordinate grid was plotted, and then the specimens were joined with a φ80x50 mm reference specimen (Fig. 4). These specimens were upset in asymmetrical and symmetrical anvils, respectively, on a hydraulic press with a pressure of 10 MN.

![Fig. 4. A specimen for strain intensity tests](image)

The distributions of local deformations on the lateral specimen surface were produced with the help of the WINSURF graphical program. For specimens upset in the asymmetrical anvils, a strain intensity distribution was obtained, which was nearly uniform. After the first upsetting, the strain intensity was equal to 0.79 at a forging radius of 20 mm from the origin of the coordination system, while 0.57 at a forging radius of 40 mm (Fig. 5a). After the second upsetting, the strain intensity was equal to 0.87 at a forging radius of 20 mm from the origin of the coordination system, this being 0.77 at a forging radius of 40 mm (Fig. 5b). The values of strain intensities on the specimen peripheries were in the range 1.13÷0.55. This inhomogeneity, as well as the visible laps caused by the conical convexities located in the working part of the anvils, are not significant, since this area is treated as an allowance for machining. This type of anvil assures a uniform material flow in all directions, thereby resulting in the occurrence of a homogeneous distribution of local strain intensities in the whole volume of the material being forged.

![Fig. 5. Distribution of strain intensities on the cross-sectional surface of a WCL steel forging deformed in radial-trapezoid anvils:](image)

- a) right-hand half of the specimen after the first upsetting,
- b) right-hand half of the specimen after the second upsetting (tilting by 90°).
5. CONCLUSIONS

It can be concluded from the computer simulations and the experimental tests carried out that the application of the asymmetrical forging process assures obtaining a uniform distribution of local strain intensities in the whole volume of a forging. This enables a rational shaping and obtaining the appropriate quality of the finished product in the specific areas of the forging.

The asymmetric forging process, proposed by the authors, provides better effects as compared with the results reported in works [1,2,3].

The performed studies indicate that it is possible to exert a substantial effect on the kinematics of material flow during the process of forming a forging by the appropriate selection of the shape of anvils.

LITERATURE