POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY
Conference Proceedings
11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

Optimisation of computer modelling free hot forging processes with help of statistic method

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The articles discusses the effect of the main parameters of the forging process and the shape of tools on inducing changes in the distribution of the values of local deformations within the volume of material being forged. As a results of the tests, the values of the main technological forging parameters have been determined, and the application of a group of tools suitable for the flat die forging of forgings has been proposed. Finding the curves regression which optimisation free hot forging process under sunspot three characteristic values intensity strain was the aim of the investigation. Optimisation of the forging process was made for three parameters: relative reduction, tilting of forging, relative feed and working surface of anvils. In this work two composition anvils has been done: radial-trapezoid anvils and shape of forcing-through radial anvils.

1. INTRODUCTION

Studies on the intended change in the distribution of strain intensities in forgings are reported in several works [1÷5]. These indicate that a significant effect on the intended distribution of strain intensities in forgings is exerted by the main forging process parameters, such as draft, feed, temperature and the shape and dimensions of anvils. The above mentioned studies aimed at the optimization of forging process parameters and the shape of anvils in order to achieve the intended fields of deformations within the forging.

In the present study, investigations were directed towards the determination of the shape and geometry of tools to obtain the strain intensity distribution as shown below in the forging during flat die forging. A theoretical study was performed for the triaxial state of deformation, the results of which were then verified in laboratory conditions.

2. MATERIAL USED FOR TESTS 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 1H18N9T corrosion resistant alloy steel conforming to the PN-89/H-78258 standard and having the chemical composition as shown in Table 1 below.

Table 1
Chemical composition of steel used for laboratory tests

Steel Grade	[Cr] %	[P] %	[Si] %	[Mg] %	[Ni] %	[S] %	[Ti] %
1H18N9T	17÷18,5	<= 0,045	<=0,8	<=2	8÷10	<=0,03	<=0,8

The laboratory and experimental tests of a model ingot with a diameter and a height of 80 mm were carried out in radial-trapezoid shaped dies shown in Figures 1 and 2.

Draft during forging in shaped dies was 15% and 25%. On completion of the first upsetting, the forging was tilted by 90 and 120° Samples were forged with relative feed 0,8 and 1,2. The feed rate was 0.75 m/s. The initial stock temperature was assumed to have been constant in the whole volume, being at 1150^{O}C. The temperature of anvils was assumed at 350°C, while the ambient temperature at 30°C. The properties of the steel were taken from the material database of the FORGE 2D® software (for the temperature range 750÷1250°C).

3. ANVILS WHICH WAS USED TO THE RESEARCH

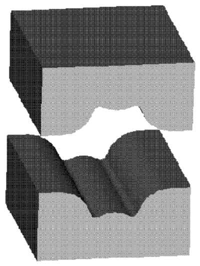

Fig. 1. radial-trapezoid anvils

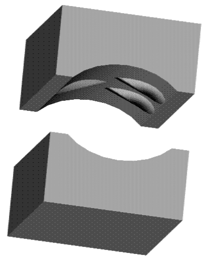

Fig. 2. Shape of forcing-through radial anvils

4. THEORETICAL ANALYSIS OF THE FORGING PROCESS

For the analysis of the forging process FORGE 3D® [6], commercial software developed at CEMEF, Ecole des Mines de Paris, was employed. The FORGE 3D program is based on the finite-elements method. It enables the thermo-mechanical simulation of the processes of plastic working of metals in the axially-symmetrical and the flat states of deformation. The calculations of the metal flow pattern and stress fields, deformation rate, deformations and temperature are conducted on the assumption of the visco-plastic model of the deformed body and 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 deformed material is described by the Norton-Hoff law:

$$S = \frac{2K}{\left(\sqrt{3\dot{\varepsilon}_i}\right)^{1-m}} * \dot{\varepsilon}; \tag{1}$$

where: s – stress deviator tensor, ε_i – deformation rate intensity, ε - deformation rate tensor, K, m – material constants.

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

$$\tau = \alpha * K\left|\Delta\nu\right|^{p-1} * \Delta\nu; \tag{2}$$

where: τ - unit vector of friction forces, α - coefficient dependent on the contact surface state, $\Delta\nu$ - velocity of slip of the material relative to the tool, p – constant.

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

$$J = \nu\int_v \frac{K}{m+1} * \left(\sqrt{3\dot{\varepsilon}_i}\right)^{m+1} * dV + \int_S \frac{\alpha K}{p+1}\left|\Delta\nu\right|^{p+1} * dS + \frac{\rho_p}{2}\int_v K\left(\varepsilon_{ij}\right)^2 * dV; \tag{3}$$

where: K, M, p – material constants dependent on temperature, ρ_p – penalty function.

The thermal part of the model utilizes the solution of the diffusion equation in the form of:

$$-k\frac{\partial T}{\partial n} = h_c\left(T - T_c\right) + \varepsilon_r * \sigma_r\left(T^4 - T_0^4\right); \tag{4}$$

where: n – unit vector normal to the surface, T_0 – ambient or tool temperature, ε_r – surface emissivity, σ_r –Boltzmann constant, h_c – heat exchange coefficient.

5. THE RESULTS OF THEORETICAL STUDIES

During the first upsetting operation in trapezoid-radial symmetrical anvils as shown in Figs. 5.1 and 5.2, deformation values from 0.17 to 0.13 were obtained in the central part of the forging, while from 0.53 to 0.17 in the external layers, see Fig. 3.

Such a distribution of deformations indicates a greater material forging ratio in the external layers of the material than in the centre. This process have been impossible to accomplish so far using anvils that have been previously in use in forging production shops. The deformation field shown in Fig. 4. has been obtained up to now via a heat treatment process. Most often, it happened that the material was forged where the maximum deformation values concentrated in the centre of the forging. We see again that the deformation field can be intentionally influenced in an arbitrary manner through the use of suitable tool shapes that force material flow in appropriate zones, thus having eventually an effect on the distribution of deformation values within the whole volume of the material deformed.

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÷0.85 were obtained in the central parts of specimen cross-sections, while in the range 0.76÷0.66 in the external specimen layers (Fig. 6).

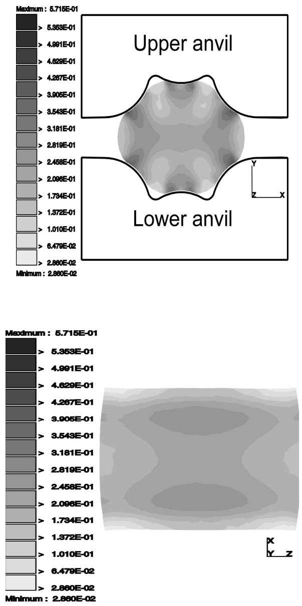

Fig. 3 Distribution of strain intensities after the first upsetting in radial-trapezoid anvils: upper diagram – view of the face surface, lower diagram – top view.

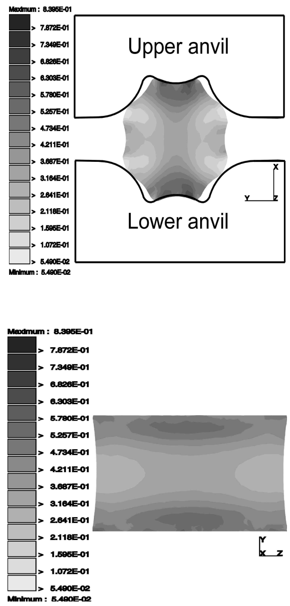

Fig. 4. Distribution of strain intensities after the second upsetting in radial-trapezoid anvils: upper diagram – view of the face surface, lower diagram – top view. Tilting by 90°.

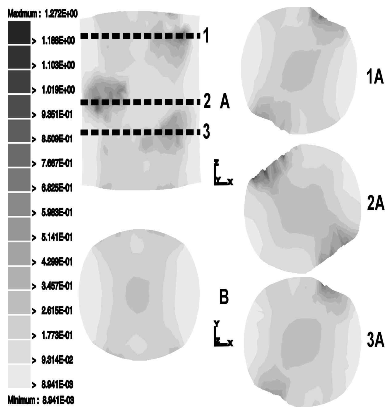

Fig. 5. Distribution of strain intensities after the first upsetting in shape of forcing-through radial anvils: A1, A2, A3 – cross-sections in the locations of conical convexities that had been made in the anvils; B – top view.

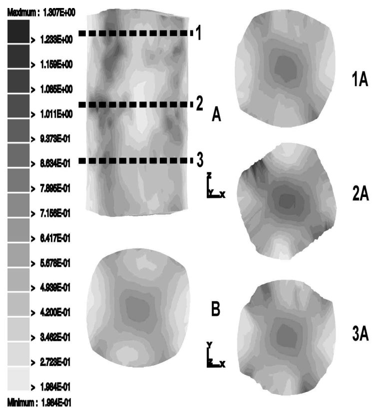

Fig. 6. Distribution of strain intensities after the second upsetting in shape of forcing-through radial anvils (tilted by 90°): A1, A2, A3 – cross-sections in the locations of conical convexities that had been made in the anvils; B – top view.

6. VERIFICATION OF THEORETICAL STUDIES

a) The results “half replica method” for the radial-trapezoid anvils in theoretical analysis

The result method 2^{3-1} for the rhombic anvils was given the following effects: (Table 2) Function was determined by quotient maximal value to arithmetic mean value:

$$Y_\varepsilon = \frac{\varepsilon_{\max}}{\bar{\varepsilon}}; \tag{5}$$

where Y_ε - quotient maximal value intensity strain to mean, ε_{max} – maximal value intensity strain, $\bar{\varepsilon}$ - arithmetic mean intensity strain value.

Table 2. The result method 2^{3-1} for the radial-trapezoid anvils

№	x0	x1	x2	x3	Y_ε
1	+	+	+	+	6,4817
2	+	-	+	-	16,7334
3	+	+	-	-	7,2727
4	+	-	-	+	3,8604

where: $x1 \in [15\%;25\%]$ relative reduction
$x2 \in [0,8;1,2]$ relative feed
$x3 \in [45;90°]$ tilting of forging

So function curves regression for the intensity strain is presented as:

$$Y_\varepsilon = 8{,}5870+6{,}9666*x1+2{,}7833*x2+0{,}9651*x3; \tag{6}$$

b) The results "half replica method" for shape of forcing-through radial anvils in laboratory analysis

The result method 2^{3-1} for the combined anvils was given the following effects:(Table 3) The function and accepted variability interval of the main parameters of forging was accepted as analogical as for rhombic anvils.

Table 3. The result method 2^{3-1} for shape of forcing-through radial anvils.

№	x0	x1	x2	x3	Y_ε
1	+	+	+	+	28,3626
2	+	-	+	-	31,9755
3	+	+	-	-	5,6407
4	+	-	-	+	7,0157

So function curves regression for the intensity strain is presented as:

$$Y_\varepsilon = 18{,}2486+11{,}1580*x1+3{,}1641*x2+1{,}7539*x3; \tag{7}$$

On the basic of the investigation of free hot forging processes it can be found, that decisive sense on the homogeneity of mechanical properties, which superscript was intensity strain, velocity strain and equivalent stress had a relative reduction, and anvils shape. Thirdly mean was tilting of forging, dependences functions (6 and 7). Material flows freely in place where he isn't bounded over deformation region. It means, that deformation energy is minimal and pressure on the material isn't intensify. In this place material attainableness the most no uniformity deformation. So the relative reduction have decisive influence in the forging process. Through the suitable deformation of region we can suitable guided the forces friction and forces pressure, they have main influence on the flowing material for the intensification of energy deformation in the place freely flowing. The suitable and considered method of giving the forging charge causing the leveling or reduction the cross-forging desirable in the forging process. From the results of simulation it can be found, that the most desirable relative reduction is value ε_h=25%. The best results has been attainment during forging in the combined anvils with the relative feed l_w = 1,2 and for tilting of forging about angle φ=90° (Fig 3.÷6). The analysis of the following process has been guided for the most often application shape anvils and the main parameters of forging, which are using in free forges at that moment.

7. CONCLUSIONS

The results of the optimisation curves regression method of the free hot forging processes can be valuable source to select correctly parameters of forging and anvils shape in objective increase quality final products. In this work the optimal relative reduction and method tilting of forging in choosing anvils shape for the homogeneity intensity strain and for the minimize zones freely flowing during deformation was proposed.

1. Comprehensive studies carried out on the flat die forging process have confirmed the existence of such values of the shape-dimensional parameters of anvil working surfaces and the values of the main technological parameters, for which the desired character of the local deformation distribution is obtained.
2. The demonstrated Norton-Hoff visco-plastic model of material deformation enables a comprehensive analysis of material flow kinematics and deformation fields in upsetting of ingots.
3. By selecting the shape-dimensional parameters of anvil working surfaces and the value of draft, we can significantly affect the following:

- location of the maximum deformations,
- values of deformation distribution irregularities, and upsetting process intensification.

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