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CHOOSING THE FORGING PARAMETERS AND TOOL SHAPE FROM THE POINT OF VIEW OF QUALITY IMPROVEMENT OF FORGING

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The article discusses the effect of symmetrical and asymmetrical forging processes on the homogenization of the values of local deformations within the entire cross-section of a forging. Theoretical studies have been performed for the plane strain deformation state, the results of which have been verified in laboratory conditions. From the tests, the values of the main technological parameters of forging have been determined and an appropriate group of tools has been proposed to be used for the anvil hammering of forgings.

Key words: *free hot forging, relative reduction, tilting of forging, shape anvils*

Odabir parametara kovanja i oblika alata sa stajališta poboljšanja kakvoće otkivka. U članku se raspravlja o utjecaju simetričnog i asimetričnog procesa kovanja na homogenizaciju vrijednosti lokalnih deformacija unutar cijelog presjeka otkivka. Provedene su teorijske studije glede stanja deformacije pri površinskom istezanju čiji rezultati su potvrđeni u laboratorijskim uvjetima. Na osnovu provedenih pokusa utvrđene su vrijednosti glavnih tehnoloških parametara kovanja i predložena je odgovarajuća grupa alata za uporabu pri kovanju otkivaka u ukovnjima.

Ključne riječi: *slobodno toplo valjanje, relativna redukcija, nagib otkivaka, oblici ukovnja*

THE AIM OF THE INVESTIGATION

Finding the curves regression which optimizes free hot forging process (three characteristic values: intensity strain, velocity strain and equivalent stress) was the aim of the investigation. Optimum of the forging process was made for three parameters: relative reduction, tilting of forging and working surface of anvils. In this work two composition anvils have been done: combined anvils and rhombic anvils [1-8].

INITIAL CONDITIONS OF THE PROCESS FOR THEORETIC MODELLING OF THE PLASTIC DEFORMATION

In the work numerical analysis of the selected schemes of free hot forging processes has been done on the basis of computer program which used finite method elements. This program was written by Prof. Grinkevich at the National Metallurgical Academy of Ukraine at the Faculty of Plastic Working Processes and belongs to this faculty. The simulation has been done for the plane strain deformation, because in this work the investigation was done only for two stages of forging process: (deformation of modelling sample and tilting of forging round a certain angle). In the work, research has been done for two compositions of anvils: rhombic and combined where open angle of anvils was $\alpha = 120°$ [1, 2]. Application of anvils with high-alloy steel was simulated, however, deformed material was the hardening steel WCL according to PN-71/H-86020. Finite mesh grid was made on the frontal plane of samples (Figure 3.). Friction coefficient for computer simulation was $\mu = 0.4$. Anvils temperature was 350 °C and initial processing temperature for samples 1150 °C. The simulation of free forging process was conducted in environmental temperature. Velocity of upper anvil was equated 15 mm/min. Moreover, the laboratory verification has been done for the theoretical model. The boundary conditions were the same as for theoretical model.

MATERIAL USED FOR THE RESEARCH

In this work the high-alloy steel WCL was simulated. The chemical composition was given in Table 1.

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Table 1. **Chemical composition of steel, which was used to the research according to PN - 71/H - 86020**

Tablica 1. **Kemijski sastav čelika koji se koristio u istraživanju određen prema PN - 71/H - 86020**

Carbon	0.42
Wolfram	0.30
Vanadium	0.50
Nickel	0.35
Copper	0.35
Silicon	1.20
Molybdenum	1.50
Chromium	5.50

The rheological properties of steel were taken from literature [8]. Computer program described properties of steel and selected parameters according to equation (1):

$$\sigma_f = \sigma_{f0} \cdot A_1 e^{-m_1 t} \cdot A_2 \varepsilon^{m_2} \cdot A_3 \dot{\varepsilon}^{m_3} \tag{1}$$

where:

σ_{f0} - basic stress,

$A_1, A_2, A_3, m_1, m_2, m_3$ - material constant dependent on temperature, velocity strain, and strain,

t - temperature,

ε - strain,

$\dot{\varepsilon}$ - velocity strain,

σ_f - stress in the function according to the upper equation.

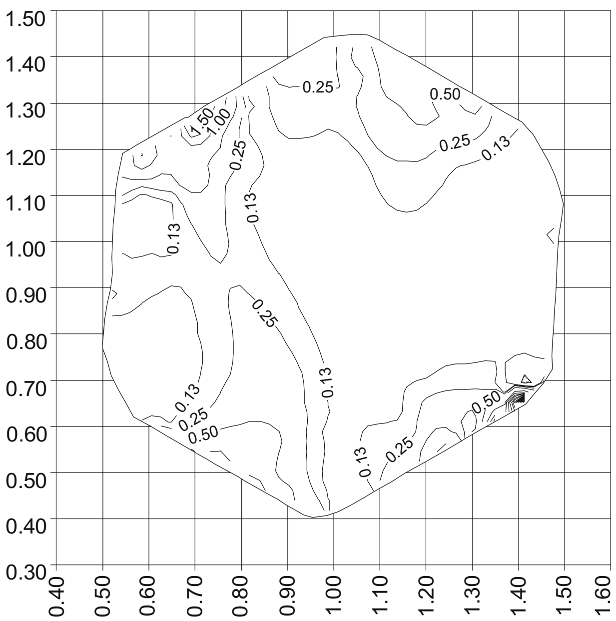

Figure 1. **Intensity strain distribution after forging in rhombic anvils, ε = 15 %, open angle of anvils α = 120°, tilting round angle φ = 45°**

Slika 1. **Intenzitet rasprostiranja deformacije nakon kovanja u romboidnim ukovnjima, ε = 15 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 45°**

The material constants are according to literature [7] equalled: σ_{f0} = 262.8 MPa; A_1 = 9.957; A_2 = 1.304; A_3 = 0.739; m_1 = 0.00230, m_2 = 0.116; m_3 = 0.131.

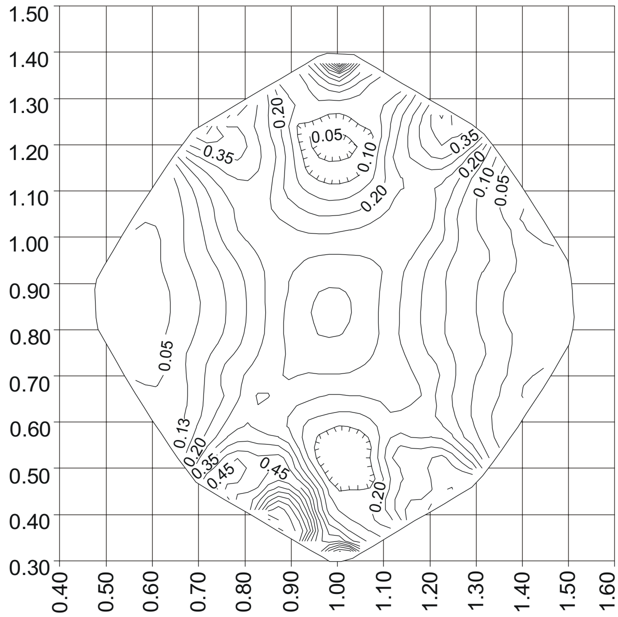

Figure 2. **Intensity strain distribution after forging in rhombic anvils, ε = 25 %, open angle of anvils α = 120°, tilting round angle = 90°**

Slika 2. **Intenzitet rasprostiranja deformacije nakon kovanja u romboidnim ukovnjima, ε = 25 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 90°**

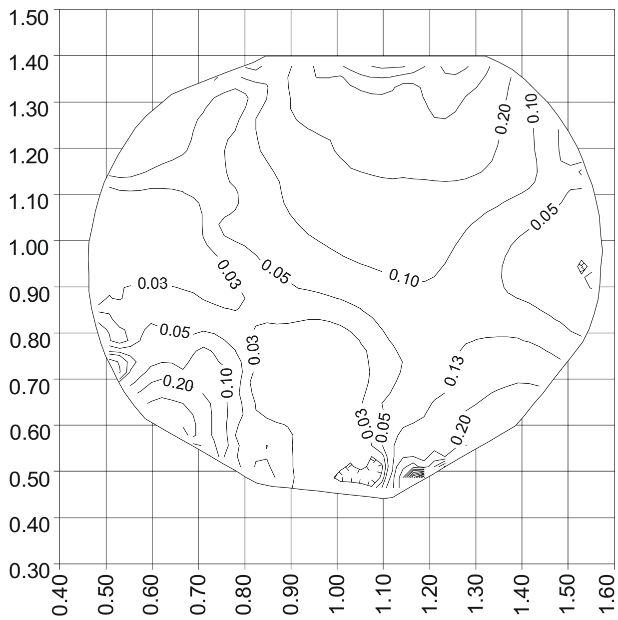

Figure 3. **Intensity strain distribution after forging in combined anvils, ε = 15 %, open angle of anvils α = 120°, tilting round angle = 45°**

Slika 3. **Intenzitet rasprostiranja deformacije nakon kovanja u kombiniranim ukovnjima, ε = 15 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 45°**

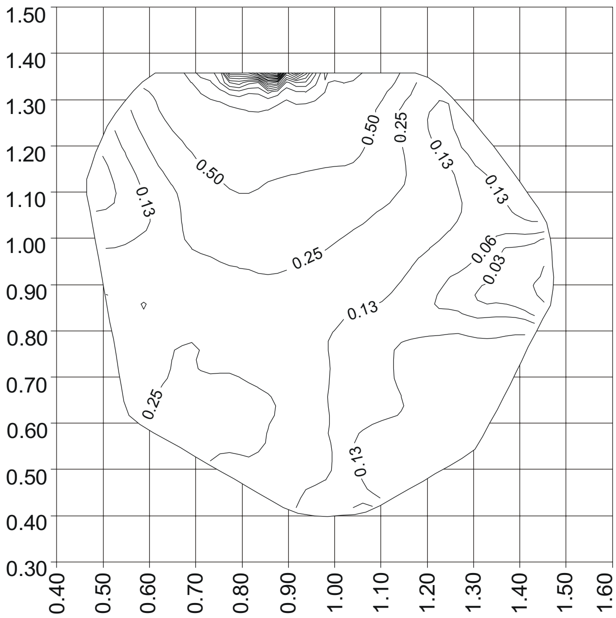

Figure 4. **Intensity strain distribution after forging in combined anvils, ε = 25 %, open angle of anvils α = 120°, tilting round angle = 90°**

Slika 4. **Intenzitet rasprostiranja deformacije nakon kovanja u kombiniranim ukovnjima, ε = 25 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 90°**

In laboratory analysis the model material with similar reological properties of WCL steel was used. WCL.

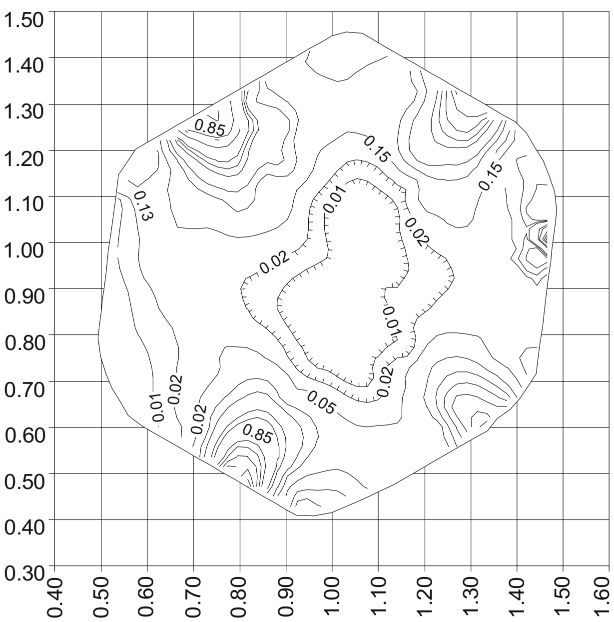

Figure 5. **Intensity strain distribution after forging in rhombic anvils, ε = 15 %, open angle of anvils α = 120°, tilting round angle φ = 45° (laboratory analysis)**

Slika 5. **Intenzitet rasprostiranja deformacije nakon kovanja u romboidnim ukovnjima, ε = 15 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 45° (laboratorijska analiza)**

THE RESULTS OF THE PROCESS OF COMPUTER MODELLING AND LABORATORY ANALYSIS

The result of the computer simulation process was determined for the nodal point of the finite mesh values: intensity strain. Criterion optimally treated by anvils shape (rhombic and combined anvils) round open angle equalled α = 120 and 90 °, tilting of forging, which equalled φ = 90 and 45 °, relative reduction ε_h = 15 and 25 %. On the basis of the simulation the isoline distribution diagrams for the intensity strain in the commercial program Surfer® V. 1-07. has been done, Figures (1.-8.). In those figures one unit plot (on X or Y axis) is equal to length of 80 mm. Moreover, the regression curves were determined on the basis of „Half Replication Results Method 2^{3-1}, dependences: (3; 4; 5; 6). As optimizing criterion, which is necessary to, made regression curves quotient of maximal value intensity strain and mean value was chosen.

The result of method 2^{3-1} for the rhombic anvils has given the following effects: (Table 2.)

Table 2. **The result of method 2^{3-1} for the rhombic anvils**

Tablica 2. **Rezultat metode 2^{3-1} za romboidne ukovnje**

N_0	x_0	x_1	x_2	x_3	Y_ε
1	+	+	+	+	6.4817
2	+	-	+	-	16.7330
3	+	+	-	-	7.2727
4	+	-	-	+	3.8604

Function was determined by quotient of maximal value and arithmetic mean value:

$$Y_\varepsilon = \frac{\varepsilon_{max}}{\bar{\varepsilon}} \tag{2}$$

where:

Y_ε - quotient of maximal intensity strain value and mean intensily strain value,
ε_{max} - maximal intensity strain value,
$\bar{\varepsilon}$ - arithmetic mean intensity strain value.

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

$$Y_\varepsilon = 8.5870 + 6.9666*x_1 + 2.7833*x_2 + 0.9651*x_3 \tag{3}$$

where:

$x_1 \in$ [15 %; 25 %] relative reduction;
$x_2 \in$ [90; 120°] open angle of anvils working surface;
$x_3 \in$ [45; 90°] tilting of forging.

The result of method 2^{3-1} for the combined anvils has given the following effects: (Table 3.)

Table 3. **The result of method 2^{3-1} for the combined anvils**
Tablica 3. **Rezultat metode 2^{3-1} za kombinirane ukovnje**

N_0	x_0	x_1	x_2	x_3	Y_ε
1	+	+	+	+	28.3626
2	+	-	+	-	31.9755
3	+	+	-	-	5.6407
4	+	-	-	+	7.0157

The function and accepted variability interval of the main parameters of forging were accepted analogical for rhombic anvils.

Table 4. **The result of method 2^{3-1} for the rhombic anvils (laboratory analysis)**
Tablica 4. **Rezultat metode 2^{3-1} za romboidne ukovnje (laboratorijska analiza)**

N_0	x_0	x_1	x_2	x_3	Y_ε
1	+	+	+	+	1.4021
2	+	-	+	-	1.9037
3	+	+	-	-	1.7538
4	+	-	-	+	1.8346

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

$$Y_\varepsilon = 18.2486 + 11.1580*x_1 + 3.1641*x_2 + 1.7539*x_3 \quad (4)$$

The linear objective function was also determined by using the Half Replication Results Method for the laboratory analysis of the process.

Table 5. **The result of method 2^{3-1} for the combined anvils (laboratory analysis)**
Tablica 5. **Rezultat metode 2^{3-1} za kombinirane ukovnje (laboratorijska analiza)**

N_0	x_0	x_1	x_2	x_3	Y_ε
1	+	+	+	+	1.7692
2	+	-	+	-	2.0000
3	+	+	-	-	1.8491
4	+	-	-	+	2.2162

So function of regression curves for the intensity strain in rhombic anvils is presented as:

$$Y_\varepsilon = 2.3152 - 0.5644*x_1 + 0.4297*x_2 - 0.5508*x_3 \quad (5)$$

and for combined anvils:

$$Y_\varepsilon = 1.9586 - 0.1495*x_1 - 0.0740*x_2 + 0,0341*x_3 \quad (6)$$

On the basis of the investigation of free hot forging processes it can be found, that decisive sense on the homogeneity of mechanical properties, whose superscript was intensity strain, had a relative reduction, and anvils shape. The third means was tilting of forging, references [3-8]. Material flows freely in place where isn't bounded over deformation region. It means, that deformation energy is minimal and pressure on the material isn't intensified. In this place material attained the most non-uniform deformation. So the relative reduction has decisive influence on the forging process. Through the suitable deformation of region we can adequately guid the forces of friction and forces pressure, they have main influence on the flowing material for the intensification of energy deformation in the place of freely flowing.

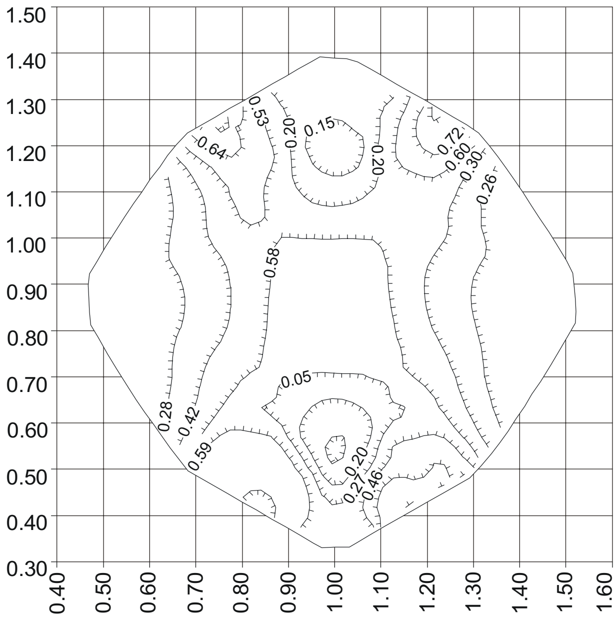

Figure 6. **Intensity strain distribution after forging in rhombic anvils, ε = 25 %, open angle of anvils α = 120°, tilting round angle = 90° (laboratory analysis)**
Slika 6. **Intenzitet rasprostiranja deformacije nakon kovanja u romboidnim ukovnjima, ε = 25 %, ukovnji s otvorenim kutom α = 120°, nagib pod kutom od φ = 45° (laboratorijska analiza)**

The suitable and considered method of giving the forging charge causes the levelling or reduction of 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 $\varepsilon_h = 25$ %.

The best results have been attained during forging in the combined anvils with the open angle of lower anvil α = 120 ° and for tilting of forging round angle φ = 90 ° (Figure 1. - 8.). The analysis of the following process has been guided for the most often application of shape anvils and the main parameters of forging, which are used in free forges at that moment.

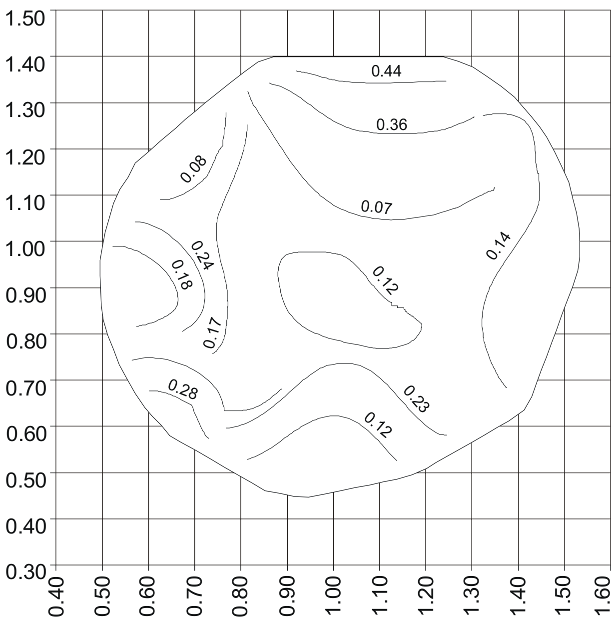

Figure 7. **Intensity strain distribution after forging in combined anvils, ε = 15 %, open angle of anvils α = 120°, tilting round angle =45° (laboratory analysis)**

Slika 7. **Intenzitet rasprostiranja deformacije nakon kovanja u kombiniranim ukovnjima, ε = 15 %, ukovnji s otvorenim kutom α= 120°, nagib pod kutom od φ = 45° (laboratorijska analiza)**

VERYFICATION OF THEORETICAL AND LABORATORY ANALYSIS

The literature investigations and theoretical analysis in nonuniform plastic flow of several regions of deformated cross-sections had been confirmed by the laboratory analysis. For laboratory analysis the material model of work-hardening curve was used. The goodness of fit of strains obtained on the way of computer simulation with laboratory testes was analyzed. This analysis was done on the basis of formed distributions of intensity strain (ε_i) and dependence of nonuniform strain on technological parameters. The standard deviation for compatibility of the laboratory and theoretical results (equation 7) was estimated:

$$\bar{s} = \sqrt{\frac{\sum_{i=1}^{n}\left(\varepsilon_{iMES}^{i} - \varepsilon_{iEKSP}^{i}\right)^2}{n-1}} \tag{7}$$

and relative standard:

$$\bar{\delta} = \sqrt{\frac{\sum_{i=1}^{n}\left(\varepsilon_{iMES}^{i} - \varepsilon_{iEKSP}^{i}\right)^2}{\sum_{i=1}^{n}\varepsilon_{iEKSP}^{2}}} \tag{8}$$

where:

ε_{iMES}^{i} - intensity strain in computer simulation,
ε_{iEKSP}^{i} - intensity strain in laboratory testes.

For good results 10 % deviation was accepted. High goodness of fit of intensity strains between theoretical and laboratory results was stated.

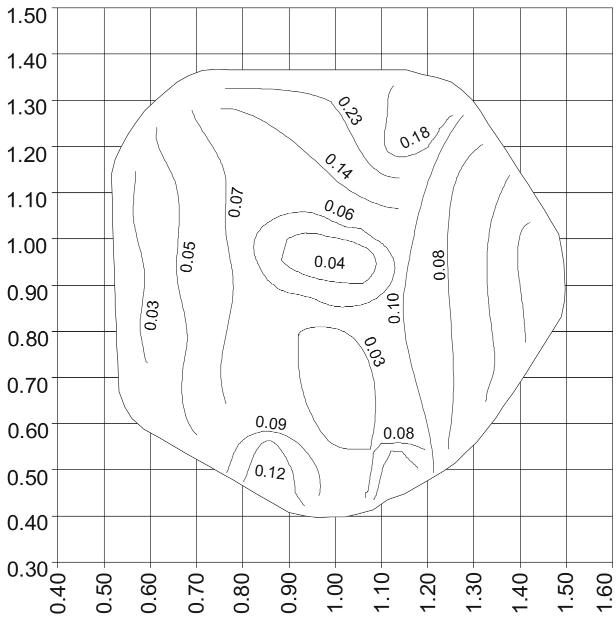

Figure 8. **Intensity strain distribution after forging in combined anvils, ε = 25 %, open angle of anvils α = 120°, tilting round angle =90° (laboratory analysis)**

Slika 8. **Intenzitet rasprostiranja deformacije nakon kovanja u kombiniranim ukovnjima, ε = 25 %, ukovnji s otvorenim kutom α= 120°, nagib pod kutom od φ = 90° (laboratorijska analiza)**

CONCLUSIONS

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

REFERENCES

[1] Ŕ. W. Altikis, M. M. Koloskow, W. A. Nazarian.: Optimisation of the free hot forging processs in the combined anvils, Kuznieczno - Sztampowoczno Proizwoctwo, No8, 1973, UDK 621.73.042., 3-8

[2] B. A. Kaledin: Distribution intensity strain deformation in the stretch forging in shape anvils, Kuznieczno - Sztampowoczno Proizwoctwo, No3, 1972, UDK 621.73.011.001.2., 10-11

[3] H. Dyja, G. Banaszek, S. Mroz, S. Berski: Effects of shape anvils forging on the intensity of local strains in selected regions of forging, Proceeding of the 4th international ESAFORM conference on material forming, Volume two, Belgium April 23-25-2001, 577-580

[4] G. Banaszek, H. Dyja, S. Mroz, M. Knapinski: Effect of symmetrical and asymmetrical forging processes on the quality of forging produced, Achievements in Mechanical and Materials Engineering, Gliwice-Sopot-Gdańsk 2000, 49-54

[5] G. Banaszek, H. Dyja, S. Berski: The influence of main parameters of the processes of forging on the internal quality of forging for steel 35HM, Inzynieria Materialowa 4, AMT Gdańsk 2001, Wydawnictwo Not i Sigma, 197-199

[6] H. Dyja, L: Lesik, G. Banaszek, S. Mróz: Intensifikacja zon deformacij w pokowkach pri kowkie w fasionnich boikach, Udoskonalenie procesiw ta obładnannia obrobki tiskom w metalurgii i maszinobuduwanni, Tematicznii zbornik naukowich prac, Kramatorsk 2001, 173-176

[7] G. Banaszek., H. Dyja., Sz. Berski: Application of CAD/CAM modelling of shape anvils in free hot forging of long product, Achievements in mechanical and materials engineering 2001, 35-39, ISBN-83-914458-4-4

[8] A. Henzel, t. Spittel: Rascet energosilovich parametrov v proces-sach OMD. Metallurgija. Moskva 1982, 51-100