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METHOD DEVELOPMENT FOR THE CALCULATION OF THE METAL DRAWING PASSES SCHEDULE TO WHICH THE HOLLOMON CURVE APPLIES

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Starting from the assumption that the hardening curve (the effective stress) during the metal cold drawing can be mathematically interpreted using a theoretical method for calculating the deformation stress state, the lower and upper bound solution, it was possible to develop a method for the calculation of the passes schedule. The theoretical analysis gave a complete insight into the process. The mathematical interpretation of the Hollomon curve was determined based on the experiments for the CuNi2Si alloy that was used for the method development and analysis.

Keywords: CuNi2Si, passes schedule, metal drawing, Hollomon curve.

1. Introduction

The paper is the result of the search for a new alloy that can be used in the production of tapes and wires in order to replace the primacy of the beryllium bronze [1]. The alloy CuNi-third alloying element can consist of: CuNiMn, CuNiAl, CuNiCr, CuNiSi, CuNiP, etc. For the experiments, CuNi2Si alloy was selected. The aim of the study was the determination of the: alloy's melting point, casting, and its chemical composition determination, microstructure investigations on the castings, its hardness, thermal conductivity and wire extrusion. Then the research went on the production of the semi-manufactured product as a starting material for the experimental part of this work. The experiment was done in such a way to allow the calculation of the mathematical expression for the construction of the Hollomon curve [2]. The hypothesis was: in the case when the hardening curve (the effective stress) can be mathematically interpreted it is possible to develop a method for the calculation of the passes schedule for cold metal drawing using the method for the calculation of the stress state deformation, the lower bound solution (LBS) and upper bound solution (UBS) [3]. The theoretical analysis of the metal drawing process interaction factors during the technological process was analyzed in order to fully understand the goodness degree and to optimize the metal drawing technological process.

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2. Theoretical part

For the analysis of the metal deformation characteristics was used the hardening curve (the effective stress curve) where the real stress σe vs. the actual or logarithmic deformation φ [2]. For most of the polycrystalline aggregate the relation between the true stress and true strain is interpreted by the equation: $\sigma = c\varphi^n$ where the c is the transformation factor and is called the strengthening factor, the n is index of the strain hardening and φ is the logarithmic strain [4]. The index n is defined from the real stresses at which the plastic instability occurs [3]. The hardening rate is: $\frac{d\sigma}{d\varphi} = cn{\varphi_m}^{n-1}$. The condition of plastic instability is: $\frac{d\sigma}{d\varphi} = \sigma \Rightarrow cn{\varphi_m}^{n-1} = c{\varphi_m}^n$. From the equality follows:

$$\varphi_m = n \tag{1}$$

Workability of the drawing deformation processes is defined with the relation [3]: $\frac{w_m}{w_{id}} = \frac{1}{\eta} = \frac{\sigma_x}{\int_0^{\varphi} \sigma \cdot d\varphi}$, and then follows:

$$\sigma_v = \frac{1}{\eta}\int_0^{\varphi} c\varphi^n d\varphi = \frac{\sigma_{e\varphi}}{\eta(n+1)} \tag{2}$$

η - coefficient of the efficiency value
w_m - internal work
w_{id} - ideal work

The boundary workability from the relationship (2) is:

$$\varphi_{\max} = \eta(n+1) = \ln(\frac{A_0}{A_1})_{\max} \Rightarrow (\frac{A_0}{A_1})_{\max} = c^{\varphi \max} \tag{3}$$

where:
A_0 - wire input section (of the conductor)
A_1 - wire output section (of the conductor)
For the passes schedule, the following applies:
Di - previous diameter of the drawing wire
D_{i-1} - next diameter of the drawing wire
and from the equation (3) follows that:

$$D_i = D_{i-1} \exp^{(-\frac{\varphi_i}{2})} \tag{4}$$

$$D_{i-1} = D_i \exp^{(\frac{\varphi_i}{2})} \tag{5}$$

The connection of the strain dependence is:

$$\varphi = \ln(1+\varepsilon) = \ln\frac{1}{1-\Psi} \tag{6}$$

ε - linear strain
Ψ - shear strain

Mean strain rate [5, 1] is:

$$w_s = \frac{\ln\lambda}{t_d} = \frac{6tg\alpha v_i \ln\lambda}{(D_{i-1}-D_i)(\lambda+1+\lambda^{\frac{1}{2}})}\left[s^{-1}\right] \tag{7}$$

and: $\varphi = \ln\lambda = \frac{A_i}{A_{i-1}}$

v_i - drawing speed
α - drawing angle

The optimum drawing angle according to Geleji - by the LBS method [7, 8] is:

$$\alpha_{op} = \sqrt{\frac{K_m \Delta A \mu}{0.77 A_a K_{fm}}}$$

and from the equation (9) follows the equation (8):

$$\alpha_{op} = \sqrt{\frac{K_{ai} \Delta A \mu}{0.77 A_a K_{sr}}} \tag{8}$$

α_{op} - angle at which the drawing force has a minimum
μ - friction coefficient

When instead of the hardening curve by Geleji figures the equation of the Hollomon curve then is: $K = c\varphi^n$ then the following applies:

$$K_{fn} = K_{sr} = K_{ai}\frac{2\varphi_{pi}+\varphi_i}{2\varphi_{pi}+\varphi_i(1+n)} \tag{9}$$

where: $K_m = K_{ai} = \sigma_e$

The optimum drawing angle by the UBS method (9, 10, 11, 12), is:

$$\alpha_{op} = \left[\frac{2}{3}\sqrt{3}\mu(1+\ln\frac{R_0}{R_f})\ln\frac{R_0}{R_f} \right]^{\frac{1}{2}} \quad (10)$$

According to von Mises' condition, the stress flow is: $\mu = \frac{m}{\sqrt{3}}$, where μ is shear coefficient.

Stress drawing [9] is:

$$\sigma_{xf} = \sigma_{xb} + \sigma_e 2f(\alpha)\ln\frac{R_0}{R_f} + \frac{2}{3}\sigma_e \left[\left((\frac{\alpha}{tg^2\alpha}) - ctg\alpha + mctg\alpha \ln\frac{R_0}{R_f} \right) + m(\frac{L}{R_f}) \right] \quad (11)$$

σ_{xb} - the inverse stress during the drawing process and during the experimental conditions equals zero.

The methods for calculating the passes schedule during the process of the cold metal drawing is subject of interest of many researchers [10, 11, 12, 13, 14, 15]. The methods are based on the experimental data, as follows:
- passes schedule with a constant reduction by the pass
- passes schedule with the decreasing single reduction
- passes schedule with the decreasing logarithmic deformation
- Fedak method
- Duckfield method.

Analyzing the method, for the calculation of the passes schedule process, in order to get the insight in their goodness degree conducts the researchers to develop new methods and evaluate them. The development of the method to which the Hollomon curve applies, and its evaluation by the LBS and UBS is possible.

3. Experimental part

The cold drawing process is influenced by many factors such as the type and the condition of the material, the value of the deformation degree, the geometry and the material of the die's contact parts, lubricant, etc.

The experimental part was done according to the plan as follows:
- the research on the die's geometry of the cone convergent part
- finding the strain hardening curve necessary for the comparative evaluation and development of the new method for setting up the technological process of the metal drawing - passes schedule

- finding the friction coefficient between the die’s material and the work piece material
- the main part of the experiment was the comparative evaluation of the methods and other relevant factors of the process.

The material for every method was propared as the semi-manufactured product made of the alloy CuNi2Si, with the diameter D_0 = 1.288 mm, dissolved annealed at 900°C for 30 minutes in a nitrogen atmosphere and quenched in water. The final wire drawing from D_0 to D_1 = 0.200 mm was performed on a laboratory drawing bench during the measurement of drawing forces and on the rotating drawing machine during the wire drawing when the properties were tested. For the experimental studies of the drawing stress the standard dies were used: the diamond and the tungsten carbide ones. The die angles were made in two variants: with the nine and seven degrees. The die selection was done according to the plan of the experiment. The strain hardening curves were necessary for the calculation of the passes schedule by the Emarnok and Duckfield method [11, 15]. The strain hardening curves were also necessary in order to introduce new products, to serve as a control group and a base for the method development and its evaluation. By a particular methodology, the preparation of the sample was done, the diameter and the appropriate logarithmic deformation of the CuNi2Si alloy. Test results are given in the diagrams in the Fig. 1 and 2.

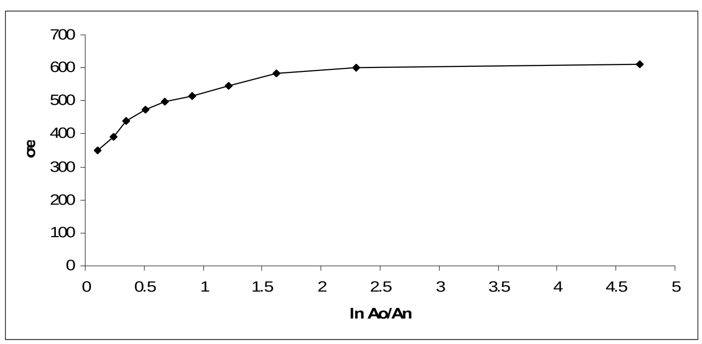

Fig. 1. Dependence of the σ_e [MPa] on the strain by the Ermanak method

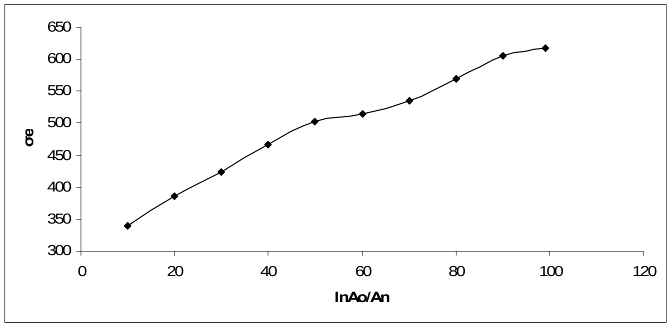

Fig. 2. The dependence of the tensile strength σe [MPa] on the strain by the Duckfield method for the CuNi2Si alloy

The effective hardening curves were obtained using the regression analysis and are depicted in Fig. 3: $K = 528.9\varphi^{0.24}$. The samples were obtained by rotational drawing machine, drawn through a standard die and the lubricant used was hypoid oil. The investigations of the drawing stress σ_{xf} for the calculations of the process and comparisons of the factors that influence the drawing process were designed with the experimental plan. The semi-manufactured product was drawn to the final diameter Dn = 0.200 mm with the calculated passes schedule in several versions in order to measure the drawing force. The passes schedule with the decreasing logarithmic strain: the A variant - a diamond die with the $\alpha = 9^o$; the B variant - the tungsten carbide die with the $\alpha = 7^o$ both with the constant partial deformation of $\varphi = 0.233$. The next ones were: the C variant-the diamond die $\alpha = 9^o$ and the D variant-the tungsten carbide die with the $\alpha = 7^o$ with the total deformation of $\varphi_u = 3.725$. Finding and comparison of the drawing stress, total energy, deformation work, the coefficient υ, the efficiency coefficient - the goodness degree η and the passes schedule is depicted in Fig. 4 and 5. The method development for the calculation of the passes schedule is based on the fact that the Hollomon curve for φ_0 has σ_0 at the D_0 for the φ_u and σ_{en} at D_u from the equation (1), n is accepted as a constantly decreasing logarithmic deformation. From the equation (3) calculated is φ_u for the relation σ_0 - σ_{en} of the "k" curve. The number of passes Z is calculated from the equation: $Z = \frac{\varphi_u}{n}$. When the input of the semi-manufactured alloy is D_0 then, the passes schedule can be calculated with the equation (4). To set a new technological process input-output the equation (5) is used. The passes schedule in that case is: $D_0 \Rightarrow D_i = 1.288$ mm and $\exp^{-\frac{0.24}{2}} = 0.8869$, z = 16 passes from the equation (4) is $D_n = 0.188$ mm. When the assumption is in real terms can be checked with the equation (6) for the wire elongation of 26% $[\varphi = \ln(1+0.26) = 0.231]$. The series can be called, as Duckfield used to name them, the „Tapel Drafts“.

4. Results and discussion

The calculation of the passes schedule experiment was carried out in the variants A and B with decreasing logarithmic deformation in twenty passes with the total strain φ_u = 3.709 [5]. While in the case of the variant C and D passes schedule calculation was carried out at the decreasing standard logarithmic strain in thirteen passes, φ = 0.2876, the total strain φ_u = 3.7204. The drawing speed was v_i = 58.4 mm s^{-1}, die cylinder L = 0.2 D, the strain rate was calculated with the equation (7). The hardening curves are depicted in Fig. 3 along with the curve "k".

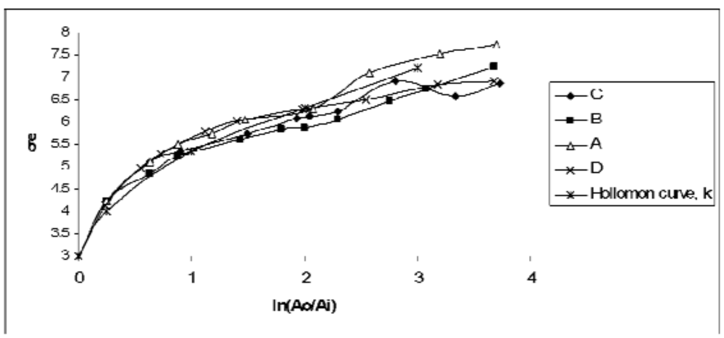

Fig. 3. The relation ln A_o/A_i versus strain σ_e for the passes schedules for A, B, C and D and the strain hardening curve k, σ_e [MPa]x10^2

In the method development for the calculation of the passes schedule, it was necessary to define the die angles in order to optimize the process. For this purpose, the parallel comparison between the experimental and theoretical analysis was done (Fig. 4 and 5).

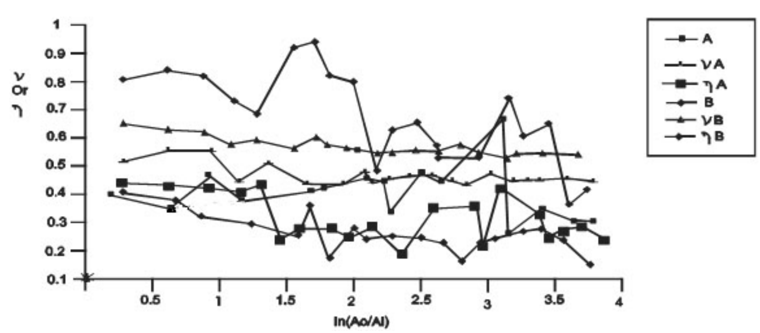

Fig.4. Arrangement of the relative drawing stress σ_{xf}/σ_e for the processes A and B, the experimental values; Arrangement of the relative drawing stress σ_{xf}/σ_e for the processes A and B, calculated values, υA and υB; The efficiency coefficient η for the A and B, calculated values, ηA and ηB

It was found that, based on the fact that the die angles are standardized possible is the following parallel course of the analysis (theoretical) for all the passes schedules (A, B, C, D). The friction coefficient μ was calculated from the equation (8) for the diamond dies and for the tungsten carbide dies from the equation (10). Then the drawing stress σ_{xf} was calculated from the equation (11). Then, the other factors of the process were calculated, the relevant drawing stress: $\upsilon = \frac{\sigma_{xf}}{\sigma_e}$ The effective stress was calculated from the curve "k". The efficiency coefficient η was calculated from the equation (2).
The experiment was done in order to:
- find a new product for the wire drawing made of the CuNi2Si alloy
- the application of the above mentioned theoretical methods in order to get the insight into the manufacturing process- the level of its goodness degree
- the method development for the calculation of the passes schedule wire drawing technological process, using the data collected from the above mentioned procedures.

The results of the analysis of the passes schedule assumption are: the diamond dies method G; the tungsten carbide dies, method H the drawing angle $\alpha_G=9^o$ and $\alpha_H=8^o$; the constantly decreasing logarithmic strain by the schedule: $\varphi_G= \varphi_H=0.24$; the friction coefficient $\mu_G=0.0648$; $\mu_H=0.1256$; the number of passes $Z_G= Z_H=16$; the total deformation degrees $\varphi_G= \varphi_H=3.725$; the semi-manufactured product with the diameter $D_0=1.288$ mm; the final product with the diameter $D_n=0.200$ mm; the relative drawing stress $\upsilon_G=0.51$; $\upsilon_H=0.68$ (Fig. 5); the efficiency coefficient $\eta_G=0.378$; $\eta_H=0.318$ (Fig. 5).

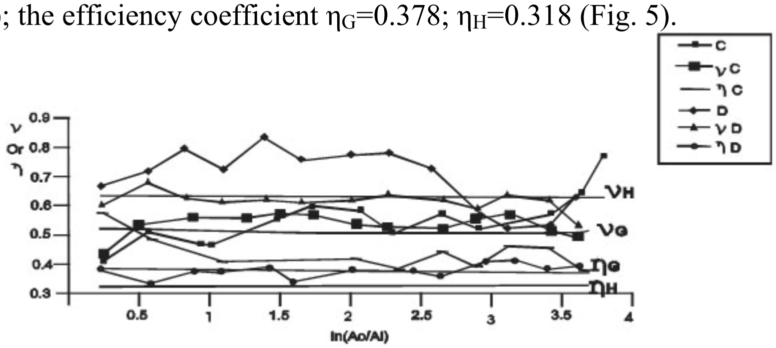

Fig 5. Arrangement of the relative drawing stress σ_{xf}/σ_e for the processes C and D, experimental value;Arrangement of the relative drawing stress σ_{xf}/σ_e for the processes C and D, calculated

values, υ_C and $\upsilon_{D;}$The efficiency coefficient η for the C and D, calculated values, η_C and $\eta_{D;}$The efficiency coefficient η for the G and H, calculated values, η_G and $\eta_{H;}$

5. Conclusions

All of the above mentioned methods used for the calculation of the passes schedule, taking into the account, also the newly developed method, can be fully analyzed and compared by the theoretical means with the diagram in the Fig. 5, presented in this paper. From the analysis given when the standard angle is near the optimal or optimal then the μ is calculated from the equation (8) for the diamond dies. From the equation (10) for the tungsten carbide dies the μ has the real values. The hypothesis that was proposed in this paper was realized with all its elements. The further experiments can investigate the quantity of the withdrawn heat, necessary lubricant and its viscosity.

R E F E R E N C E S

[1]. *Živko Jokovic*, Uticaj termodinamičkog režima prerade na osobine Cu-Ni-Si legura (The influence of the thermodinamical regime of manufacturing on the characteristics of the Cu-Ni-Si alloys), M. Sc. Thesis, Faculty of Metallurgy and Technology, Belgrade, 1992

[2]. *Dj. Drobnjak*, Fizička metalurgija – Fizika čvrstoće i plastičnosti 1, TMF, Beograd,1980.

[3]. *V. Vujovic*, *D. Vilotic*, *M. Plancak*, *I. Trbojevic*, Istraživanje postojanosti profila matrice i mogućnosti primene hidrostatičkog vučenja žice, FTN, Novi Sad, 1976.

[4]. *J. H. Hollomon*, “Tensile Deformation“, in Transactions of the American Institute of Mining, Metallurgical and Petroleum Engineers, **vol. 162**, 1945, pp. 268-290.

[5]. *M. Z.Emarnok*, Volochenye cvetnych metallov, Metallurgiya, Moskva,1982.

[6]. *B. Avitzur*, “Flow Characteristics through conical convergent dies“, in ASME Journal of Engineering for Industry, Series B, **vol. 88**, 1966, pp. 410-420.

[7]. *S. Geleji*, “The Calculations of Forces and Power Requirements for the Rolling of Metals“, in The Engineers Digest, London, 1948, pp. 126-129.

[8]. *S. Geleji*, “Die Berechnung der Kräfte und des Kraftbedarfs bei der Formgebung im bildsamen Zustande der Metalle“, in Akadémiai Kiadó, Budapest., 1952, 248.

[9]. *B. Avitzur*, “Analysis of wire drawing and extrusion through conical dies of small cone angle“, in Trans. ASME, Journal Eng. Ind., Series B, **vol. 85**, 1963, pp. 89-96.

[10]. *И. Л. Перлин*, *М. З. Ерманок*, Теория волочения, М.: Металлургия, Москва, 1971.

[11]. *М. З. Ерманок*, Применение безоправочного волочения при производстве труб, М-во цв. металлургии СССР, Центр. науч.-исслед. ин-т информ. и техн.-экон. исследований цв. металлургии, Москва, 1965.

[12]. *V. Sijacki-Zeravcic*, *M. Rogulic*, *V. Milenkovic*, “Influence of deformation on the mecanical properties, texture and microstructure of an AlCuMg alloy“, in Zeitschrift fuer Metallkunde/Materials Research and Advanced Techniques, **vol. 83**, 1992, pp. 110-114.

[13]. *V. M. Milenkovic*, Uticaj mehaničkog režima hladnog valjanja na dinamičko oporavljanje OFHC bakra (The influence of the mechanical regime of the cold rolling on the dinamical recovery of the OFHC copper), PhD thesis. Belgrade, 1971.

[14]. *J. Fedak*, "Calculating die sets for wire-drawing", Wire Industry, **vol. 54**, 1987, pp. 564-567.

[15]. *B. J. Duckfield*, "The theory and practice of wire drawing—Part I and II", Wire Industry, 1973, pp. 40.