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ANALYSIS OF THE DEFORMATION STATE OF THE HOLLOW AL-PROFILES EXTRUSION PROCESS BY THE MICROSTRUCTURAL METHOD APPLICATION

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ABSTACT

The study of the structural state of the after-deforming material can provide a lot of useful information concerning the concrete plastic deforming process. On the basis of an adequate analysis it is possible to determine the stress/strain ratio in the plastic deformation zone and the material flow kinematics as well as the degree of work-hardening of the material, structural defects and structure transformation, the limit deformability of the material and so on. For the deformation state analysis the microstructural method has proved itself to be a very efficient and simple one. However, the application of this method has so far been mostly related to the process of deforming steel materials in the cold state. The paper shows that the method can be successfully applied to aluminium and its alloys as well just as it can be used for very intricate deformation processes such as the Al-profiles extrusion in the hot state. The developed software provides for a fast, easy and accurate calculation; it can also serve as one of the modules in the automated system for experimental data measurement and processing.

1. INTRODUCTION

In the study of the material forming processes there are analytical, experimental and experimental-analytical methods. Of the well-known methods for analyzing kinematics of the material flow as well as for determining the stress/strain state the most widely applied is the method of measuring (coordinate) grids (E.Siebel, P.O.Paškov, G.A. Smirnov-Aljajev, I.P.Renne, W.Voelkner and others.) [1,2]. This method belongs to the experimental-analytical ones and it is based upon the deformation plasticity theory (Lévy-von Mises equations) or the plastic flow theory (Prandtl-Reuss equations). The measuring grid method has found such a wide application primarily due to its relatively simple experimental procedure and its processing of experimental results. However, the measuring grid method has also a set of shortcomings and limitations such as:

- necessity of cutting into a billet (this procedure defines in advance only one possible measuring plane on the workpiece); on the other hand, the workpiece material's continuity is broken thus leading to the fact that the deforming conditions in the experiment and in the real process are somewhat different),

- relatively large cells of the measuring grids (it limits the number of measurement points in the plastic deformation zone thus also reducing the precision of the qualitative-quantitative estimate of the deformation state; likewise, the method remains inapplicable with small thickness of the workpiece walls or in intricate sections with sharp transition radii (due to great distortions of the grid cells)),

- cut-into surfaces must remain flat even after deforming (this condition can virtually be fulfilled only with plane or axi-symmetric deformation processes),

- measurement points on the workpiece are in the coordinate system apexes and therefore, they cannot be randomly chosen (this fact causes difficulties in presenting the measurement results and calculations),

- deformation state cannot be determined along the contours of the plastic deformation zone,

- the strain history cannot be followed during the deformation process since only the initial and final geometry of the measuring grid cells is known,

- accuracy of measurements and calculations depends, to a considerable degree, upon the grid cell size, the accuracy of its placing and reading, etc.

Some variants of the mentioned methods (namely, the visioplasticity method, the moire' (grid-analyzer) method) have eliminated a certain number of the above-stated shortcomings, but, still, these methods themselves have their own shortcomings and limitations [2,3,4,5,6].

Hence, it can be concluded that the measuring grids method application in the analysis of the extrusion processes of intricate full and (especially) hollow Al-profiles is entirely limited.. This is the reason why for the analysis of this and similar deformation processes the microstructural method (G.A.Smirnov-Aljajev, E.I.Uljanov, S.Šenkar and others) [1,7] can be recommended. This method is efficient, relatively simple, with a series of positive characteristics such as:

- analysis and calculation refer to the "material" point (the comprised space (area) can amount to several dozens of micrometers so that the number of experimental points can be very large),

- choice of the experimental points' position in the plastic deformation zone is random (thus providing for a precise presentation of the deformation distribution per sections or along the material flow trajectories),

- physical separation of the billet is not necessary (there is no interruption of the workpiece material continuity while the choice of the measurement plane position is random),

- measurements can be also done in the close vicinity of the tool contour, at the plastic deformation boundary zone, at the places where internal cracks appear, etc.,

- it is possible to make a comparative analysis of the workpiece material (size, shape and direction of the crystal grains as well as the inter-crystal substances composition, etc.), and,

- for the determination of the stress/strain state the known plasticity theory relations can be used.

The only real shortcoming of this method is greater dissipation of the results which is a consequence of the structure non-uniformity, of the defects in the workpiece structure and of the errors in measurement but all this can be overcome by a greater number of repeated tests as well as a greater number of measurement around the given material point.

Finally, many authors have applied different forms of the microstructural analysis for different processes of the material forming for the sake of making a correlation between the structure and the plastic properties of the material, that is, between the structure and the technological parameters of the material forming process. [8,9,10,11,12,13,14,15].

2. THEORETICAL APPROACH

The microstructural method developed by G.A.Smirnov-Aljejev [1] is based upon the assumption that a random material particle of the deformable body which in its initial state is of spherical form (of diameter d) after the deformation process is transformed into a three-axes ellipsoid (semi-axis a,b,c). The longitudinal sections of the ellipsoid and the sphere in plane (x,y) have the form of ellipse, that is, circle (Fig. 1).

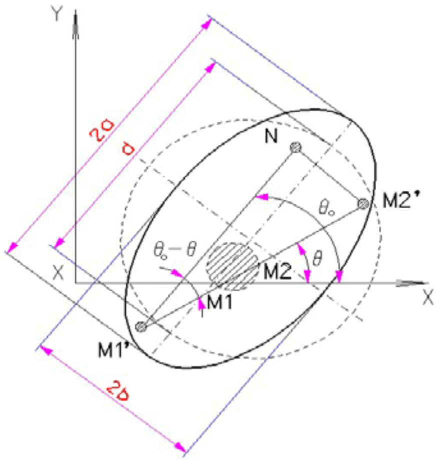

Fig. 1. Transformation of the Material Particle of the Spherical Form into the Ellipsoid

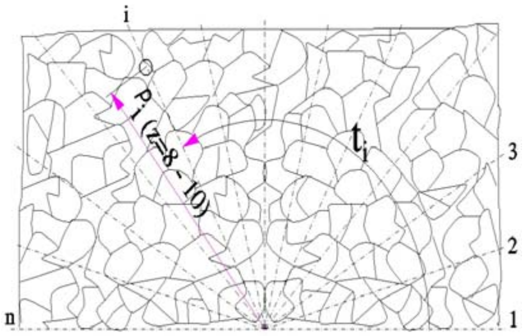

Fig. 2. Positioning of the Measurement Directions and the Ways of Measurement Radius Around the Observed Point

According this method for determining the deformation state parameters it is necessary to determine the relationship between the initial and the final distance of the two close material points of the body as defined by the following relation [1]:

$$(\rho_0/\rho)^2 \equiv E = D + A\cos 2t = \frac{Q_k(n+C_2)-2Q_aC_1}{n(n+C_2)-2C_1^2} + \frac{Q_k-nD}{C_1}\cos 2t \qquad (1)$$

where:

A,D,C_1....Q_a -constants,

n - number of randomly chosen measurement directions through the observed point of the workpiece in the plastic deformation zone (n=5 ÷15),

t - angles of the chosen measurement directions with respect to the x-axis (0°-180°),

ρ_0- radius (average) around the randomly chosen points of the workpiece for the chosen number of crystal grains (z=8 ÷10),

ρ - current radii for the chosen measurement directions (n) and for the chosen number of crystal grains (z).

The unknown constants are determined from the relations:

$$Q_a = \sum_{i=1}^{n}(\rho_0/\rho)_i \cos 2t_i\,;\; Q_k = \sum_{i=1}^{n}(\rho_0/\rho)_i^2\;;C_1 = \sum_{i=1}^{n}\cos 2t_i\;;\; C_2 = \sum_{i=1}^{n}\cos 4t_i \qquad (2)$$

Particular parameters given in expressions (1) and (2) are given in Fig. 2. On principle, the ways of measuring the radius on the workpiece (ρ_0) and of the current radii on the workpiece (ρ) are identical.

The component deformations, the equivalent deformation and the Lode-Nadai coefficient are all determined according to the formulae:

$$\varphi_a = -0{,}5\ln(\rho_0/\rho)^2_{min} \quad ; \quad \varphi_b = -0{,}5\ln(\rho_0/\rho)^2_{max} \quad ; \quad \varphi_c = -(\varphi_a+\varphi_b)$$

$$\varphi_e = \frac{\sqrt{2}}{3}\sqrt{(\varphi_1-\varphi_2)^2+(\varphi_2-\varphi_3)^2+(\varphi_3-\varphi_1)^2} \quad ; \quad \nu_\varphi = \frac{2\varphi_2-\varphi_1-\varphi_3}{\varphi_1-\varphi_3} \qquad (3)$$

For the experimental data approximation the regression function of form (1) is used under the assumption that in the meridian section of the workpiece the measurement direction (0^0÷180^0) overlaps the main direction (axis) of the deformation. If this condition is not fulfilled the general form of the regression analysis should be used [1,7,8].

FIG. 1. EXPERIMENTAL PROCEDURE AND ANALYSIS

The application of the above-described method has been tested on the example of the identical sense extrusion of three hollow profiles - tubes, namely of circular, square and rectangular form. For the sake of comparing the results the profile cross-sections were the same as well as the billet dimensions. The other deformation conditions were also the same. The alloy AlMgSi0.5 was chosen as a representative of all the Al-alloys used for making the most intricate full and hollow profiles by the extrusion procedure [16,17].

For the extrusion of the given hollow profiles the experimental bridge tools were used, namely those that were so designed that it was possible to draw out the remaining material from their hollows (that is, the part that was within the plastic deformation zone). Besides, the extrusion process was carried out in the real manufacturing conditions.

Because of the specific nature of the given technological procedure for making Al-profiles no lubrication was done.

For the needs of testing and measuring the first thing to do was to make microsamples with respect to the meridian sections of the billets and workpieces (in the plastic deformation zones). The microstructure of thus prepared samples is camera-recorded (Fig. 3, Fig. 4).

In Fig 5. Is given a longitudinal section of the workpiece in the plastic deformation zone. The given grid is of fictional character and it only serves for defining measurement points' location. The determination of location of each measurement point, measurement directions as well as currtent radii for the chosen number of the crystal grains is done by the microscope.

For the needs of measurement and calculations the following parameters are accepted in advance: $n=7,\Delta t=30^\circ,z=10$.

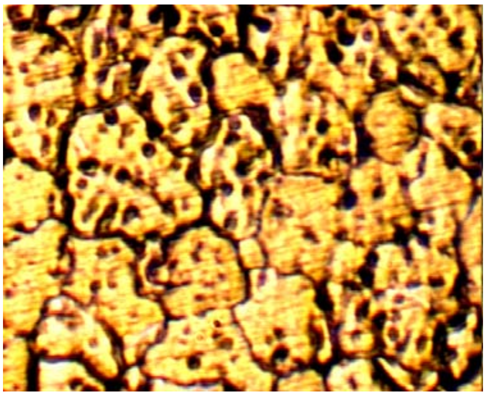

Fig. 3. Billet Microstructure (50x)

Fig. 4. Workpiece Microstructure (100x)

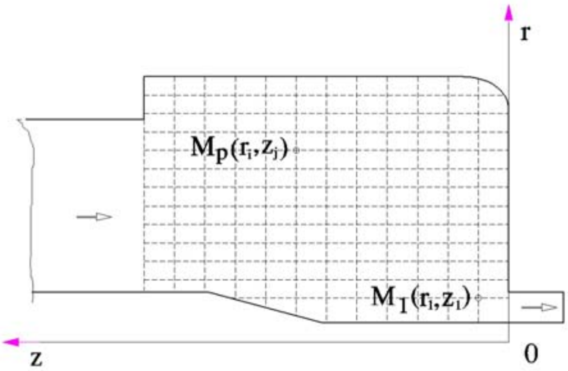

Fig. 5. Measurement Places Distribution in the Plastic Deformation Zone

The initial radius is determined as an arithmetic average value of the measurement results upon a greater number of billets. On the basis of the measured values of the current radius at each measurement point of the workpiece in the plastic deformation zone it is possible to determine all the unknown constants in relations (1) and (2) as well as the deformation state parameters according to formulae (3). The entire calculation is done by using the MICROS program whose algorithm is shown in Fig. 6. Among other things, the program is used for ordering the main (logarithmic) deformations according to their algebraic value $(\varphi_1 > \varphi_2 > \varphi_3)$. In the general case, this ordering is necessary for the sake of determining the equivalent deformation and the Lode-Nadai coefficient.

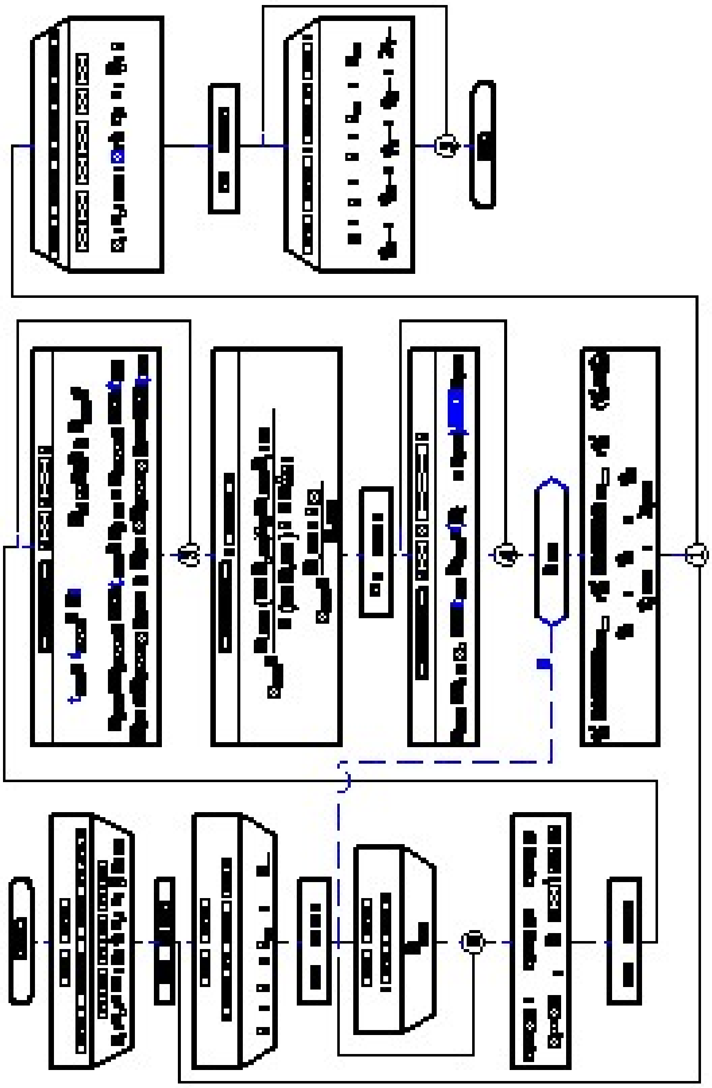

Fig. 6. Flow chart of the MICROS program

For checking upon the measurement accuracy it is necessary to determine, at each measurement point, the degree of agreement of the experimental points with the regressive function (2) (Fig. 7). If the agreement is not satisfactory, it is necessary to increase the number of measurement directions at a given point or/and reject any experimental result that departs essentially from the regressive curve as a “crude” error in measurement; the calculation procedure should be repeated then. By applying the above-mentioned computer program the repeated procedures do not represent any difficulty whatsoever.

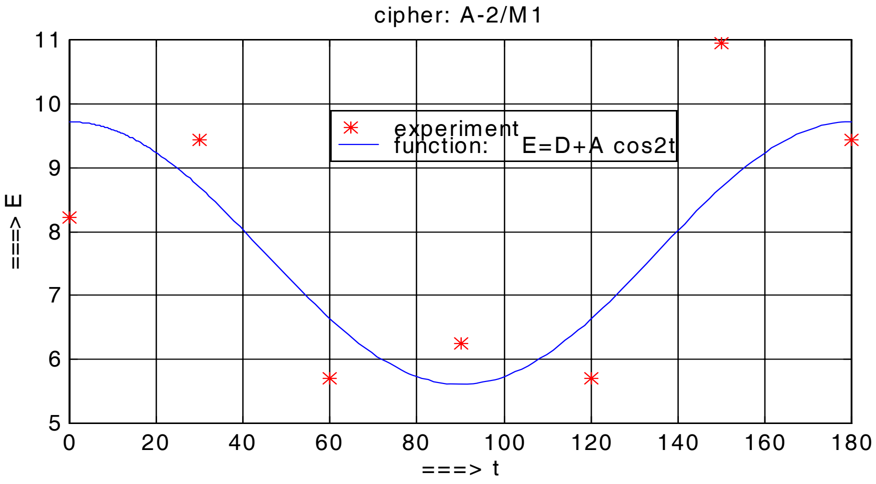

Fig. 7. Analytical Approximation of Experimental Data

A partial presentation of the experimental data is given in Table 1 together with the basic technological parameters. The calculation results provide for a qualitative and quantitative analysis of the deformation state in the plastic deformation zone.

Tab.1. State of deformation for forward extrusion of hollow Al-profiles in bridge tool

TECHNOLOGICAL PARAMETERS	
Extrusion material:	AlMgSi0.5
Profile/tool cipher:	ZP-KR / A-2-KR
Relative thickness of wall (or s_{max}/s_{min}):	0.135 (-)
Cross-section area of profile:	500.0 (mm^2)
Weight per unit lenght of the profile:	0.993 (kg/m)
Billet diameter/lenght:	220/820 (mm)
Natural (logarithmic) degree of deformation:	4.48 (-)
Initial billet/tool temperature:	495/460 (^0C)
Extrusion speed:	10.5 (m/min)

RESULTS OF COMPUTING					
p	i j	r_i z_j	φ_a φ_b φ_c	φ_e	ν_φ
1	1 1	5.00 3.00	-0.862 -1.137 1.996	2.005	-0.825
2	2 1	12.00 3.00	-0.529 -0.733 1.262	1.267	-0.795
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7	2 3	12.00 22.50	1.148 1.022 -2.170	2.171	0.924
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12	3 4	19.00 42.00	1.438 0.857 -2.294	2.319	0.689
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4. CONCLUSION

The research presented in this paper has shown that the microstructural method can be successfully applied to an analysis of intricate processes of the material forming, processes such as the hollow Al-profiles extrusion. The obtained results are within the expected boundaries for the given analyzed extrusion procedures.

On the basis of the quantitative-qualitative analysis of the deformation state and of the workpiece microstructure in the plastic deformation zone it is possible to make an adequate choice of tools, tool geometry and temperature-velocity forming conditions.

With the modern computer systems it is also possible to make the given measurement procedure and the presentation of the obtained results fully automatic. For this purpose the developed software shown in the paper can also be used.

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ANALIZA DEFORMACIONOG STANJA PROCESA ISTISKIVANJA ŠUPLJIH AL-PROFILA PRIMENOM MIKROSTRUKTURNOG METODA

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REZIME

Proučavanje strukturnog stanja materijala nakon deformisanja može da pruži mnoštvo korisnih informacija o konkretnom procesu obrade plastičnim deformisanjem . Na osnovu adekvatne analize moguće je utvrditi naponsko-deformacione odnose u zoni plastičnih deformacija i kinematiku tečenja materijala, zatim stepen deformacionog ojačanja materijala, strukturne defekte i tranformacije strukture, graničnu deformabilnost materijala i sl.

Za analizu deformacionog stanja mikrostrukturni metod se pokazao kao veoma efikaasan i jednostavaan metod. Međutim, dosadašnja primena ovog metoda odnosila se, uglavnom, na procese deformisanja čeličnih materijala u hladnom stanju. U priloženom radu je pokazano da se ovaj metod može uspešno primeniti i na aluminijum i njegove legure i na veoma složene procese obrade deformisanjem, kao što je istiskivanje šupljih Al-profila u toplom stanju.

Razvijeni softver omogućava brz, lak i tačan proračun i može poslužiti kao jedan od modula u automatizovanom sistemu za merenje, obradu eksperimentalnih podataka i prikaz dobijenih rezultata.