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ANALYSIS OF THE EFFECT OF DIE SHAPE ON THE STATE OF STRAIN IN THE PROCESS OF EXTRUSION OF THIN-WALLED ALUMINIUM SECTIONS

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A theoretical analysis of the effect of die shape on the stress - strain state during hot extrusion of T-section bar of two different aluminium alloys has been carried out in this study. A finite element method-based program, was used for modelling the extrusion process. Tests were carried out to obtain optimal process parameters of extrusion of T-shaped section, at which no deformation of the section occurs. The effect of the antechamber height and the shape as well as arrangements of the die channel on the geometrical shape of the extruded product have been determined.

Key words: *aluminium, process of extrusion, thin-walled section*

Analiza utjecaja oblika matrice na stanje naprezanja u procesu istiskivanja alumijiskih profila s tankim stjenkama. U ovoj studiji je razrađena teorijska analiza utjecaja oblika matrice na naprezanje i deformiranje pri toplom istiskivanju T-profila dviju različitih aluminijskih slitina. Za modeliranje procesa istiskivanja rabljen je program temeljen na metodi konačnih elemenata. Provedena su ispitivanja za optimalne parametre procesa istiskivanja T-profila pri kojima nije došlo do nikakvih deformacija profila. Utvrđen je utjecaj visine pretkomore te oblika i izvedbi kanala matrice na geometrijski oblik istiskivanog proizvoda.

Ključne riječi: *aluminij, proces istiskivanja, tankostjeni profili*

INTRODUCTION

When developing a technology of extrusion of aluminium products, one of important tasks is the selection of die shape - antechamber parameters, such as the height of the chamber and its surface area. The experimental determination of these parameters, involving the mechanical correction of the die, is expensive and not always effective. Therefore, developing methods of computer simulation for these processes is an very important task. In computer simulations of the three-dimensional metal flow, a problem of the optimization of die chamber shape arises, which requires a large number of simulations, each of which lasting about 10 to 20 hours. A reduction in the number of simulations can be achieved by using the methods of optimization of experimental study conditions.

A theoretical analysis of the effect of die shape on the state of strain during hot extrusion of T-shaped section has been carried out in the study, along with the optimization of this process.

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CHARACTERISTICS OF MATERIALS USED IN INVESTIGATION

Extrusion3, a finite element method-based program, was used for modelling the extrusion process [1]. The modeling was carried out according to the scheme shown in Figure 1. The input data for the generation of a three-dimensional grid were graphical files representing the geometrical dimensions of the section and container, produced using the AutoCAD program, and the rheological properties of the material, friction conditions, extrusion speeds, and the values of working strip retardation angles. The extrusion process parameters taken for computations are given in Table 1. The theoretical analysis of the process required the definition of the rheological

Table 1. **Extrusion process parameters**
Tablica 1. **Parametri procesa istiskivanja**

Extrusion process parameters	
Extrusion speed	3 mm/s
Ingot temperature	500 °C
Tool temperature	450 °C
Friction coefficient	μ = 0,8
Heat exchange coeffic.	4000 W/m^2°C
Container length	100 mm

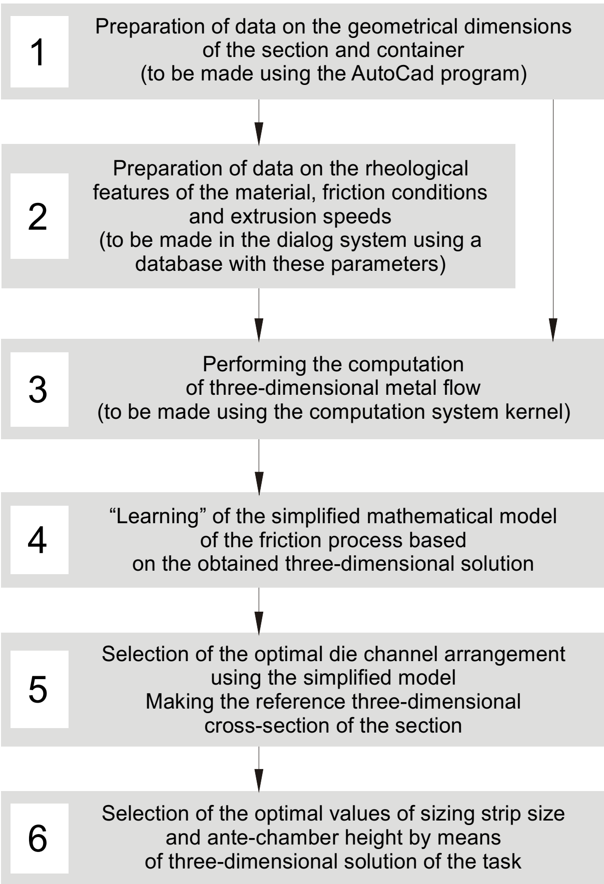

Figure 1. **Structure of the comprehensive three-dimensional model of section extrusion**
Slika 1. **Struktura razgrananog 3-dimenzionalnog modela istiskivanja profila**

properties of the examined alloys. For the description of the dependence of yield stress on the strain parameters the following relationship was used [2]:

$$\sigma_p = K_0 \cdot A_1 \exp(-m_1 t) A_2 \varepsilon^{m_2} \cdot A_3 \varepsilon^{m_3} \qquad (1)$$

where:

σ_p - yield stress / MPa,
ε - strain intensity,
ε - strain rate,
K_0, A_1, A_2, A_3, m_1, m_2, m_3 - material constants for the alloys,
t - temperature /°C.

Material constants for the alloys used in the investigation are given in Table 2.

Computer simulations were carried out for the following conditions:

- antechamber height, h = 8 to 16 mm,
- antechamber surface area, S = 2260,93 to 3720,25 mm^2,
- shift of the die chamber on the tool surface, l = 5 to 7 mm.

Table 2. **Material constant of the alloys investigated [2]**
Tablica 2. **Konstanta materijala ispitivanih slitina [2]**

AlCuMg		99,5 % Al	
K_0 = 123,4		K_0 = 38,0	
A_1 = 123,4	m_1 = 0,00438	A_1 = 4,876	m_1 = 0,00396
A_2 = 5,693	m_2 = 0,022	A_2 = 1,49	m_2 = 0,173
A_3 = 0,771	m_3 = 0,113	A_3 = 0,775	m_3 = 0,111

Modelling of the extrusion process was performed according to the scheme given in Table 3.

Table 3. **Variants of modeling of the extrusion process**
Tablica 3. **Varijante modeliranja procesa istiskivanja**

Simulation No.	Antechamber height X_1	Antechamber surface area X_2	Shift of the die channel on the tool surface X_3
1	+	+	+
2	−	+	+
3	+	−	+
4	−	−	+
5	+	+	−
6	−	+	−
7	+	−	−
8	−	−	−

Figure 2. shows the geometrical dimensions of the die channel antechamber used for investigation. The investigation was performed for ¼ of the charge.

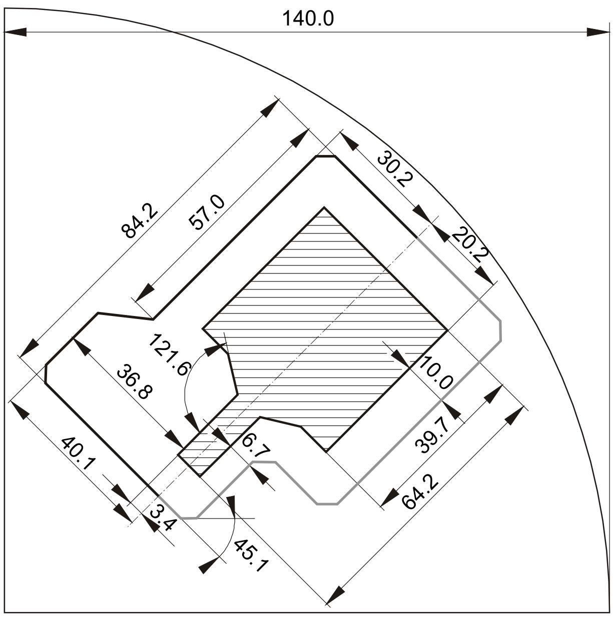

Figure 2. **Geometrical dimensions of the antechamber and channel in the quarter of the die surface area**
Slika 2. **Geometrijske dimenzije pretkomore i kanala u četvrtini područja površine matrice**

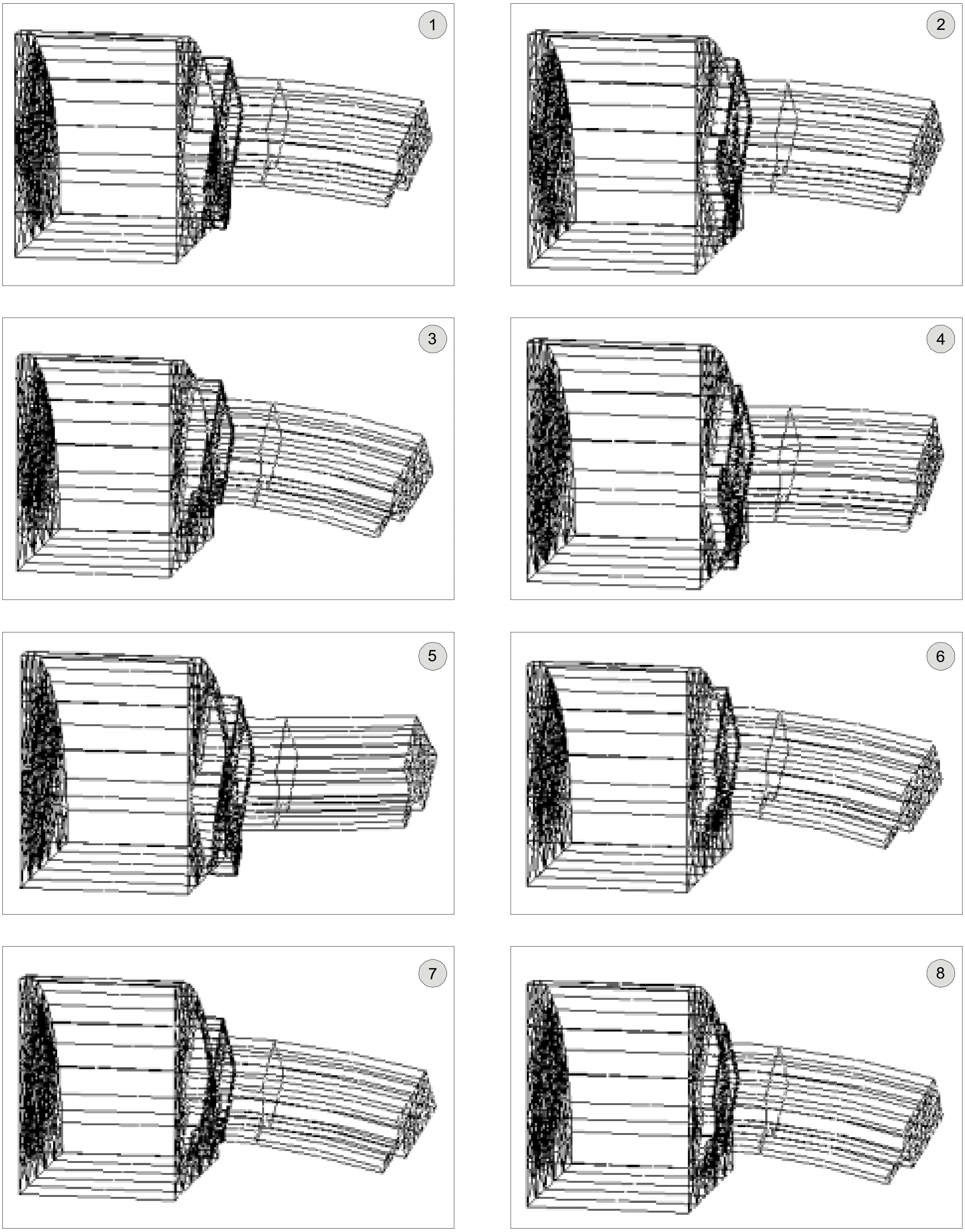

Figure 3. **Finite-elements grid of the section after the process of extrusion of the AlCuMg alloy (1 to 8 - according Table 3.)**
Slika 3. **Rešetka konačnih elemenata profila nakon procesa istiskivanja slitine AlCuMg (1 do 8 prema tablici 3.)**

INVESTIGATION RESULTS AND DISCUSSION

As a result of performed computer simulations, a three-dimensional solution of the extrusion of T-shaped section of selected aluminium alloys was obtained. The finite-elements grid for the considered variants of the performed simulations of the process of extrusion of the 99,5% aluminium alloy is shown in Figure 3.

It can be found from the investigation results that the pattern of metal flow during extrusion is similar for the both alloys (Figure 3.).

The data shown in Figure 3. indicate that, for the AlCuMg alloy for 7 variants of simulation, the metal flow velocity in the thicker part of the strip is higher than the velocity in its thinner part, and therefore a bend of the section results. For one variant, see Figure 3. a straight section was obtained.

The coordinate values given in Table 4. served for the quantitative determination of the strip bend defined by the parameter *a* for respective simulation variants, with different criteria of arrangement of the die channel and antechamber shape on the die surface.

Table 4. **Coordinates of points used for the determination of the magnitude of section bend**
Tablica 4. **Koordinate točaka rabljenih za određivanje magnitude profila koljena**

Point coordinates		Variant 1	2	3	4
x_1		45,38	45,38	45,38	45,38
y_1		40,80	40,80	40,80	40,80
z_1		196,00	196,00	196,00	196,00
99,5 % Al	x_2	36,12	37,88	29,46	30,09
	y_2	33,04	34,15	25,05	26,01
	z_2	93,04	94,22	87,69	89,80
AlCuMg	x_2	35,99	37,66	28,93	29,85
	y_2	32,99	33,93	25,07	26,44
	z_2	92,76	94,10	87,47	89,45
Point coordinates		Variant 5	6	7	8
x_1		36,9	36,9	36,9	36,9
y_1		32,32	32,32	32,32	32,32
z_1		196,00	196,00	196,00	196,00
99,5 % Al	x_2	28,65	30,05	22,18	22,21
	y_2	46,43	26,71	18,38	18,19
	z_2	88,51	93,82	86,32	88,37
AlCuMg	x_2	28,20	35,25	21,59	21,84
	y_2	39,39	31,04	18,26	18,23
	z_2	90,89	94,60	86,22	88,23

The magnitude of the parameter *a* was determined from the relationship below:

$$a = \frac{\Delta L}{L}$$
$$\Delta L = L_2 - L_1$$
$$L_1 = \sqrt{x_1^2 + y_1^2}$$
$$L_2 = \sqrt{x_2^2 + y_2^2}$$
$$L = z_2 - z_1 \quad (2)$$

where:

z - extrusion direction,
x, y - directions perpendicular to the extrusion direction.

Based on computer simulations carried out for the investigated alloys with specified extrusion conditions and parameters, the radius of curvature of the section was determined for different die variants; the results are summarized in Table 5. The "+" sign indicates that the bend has occurred as a result of a faster metal flow from the thicker strip segment, whereas the "–" signs shows that the bend has formed on the thinner strip side.

As can be seen from the data in Table 5., the smallest bend of the AlCuMg alloy section has been obtained for the 5th simulation of the section extrusion process with the height of the antechamber equal to 16 mm and its surface area of 3720,2 mm^2, which corresponds to the variants of the maximal values of these factors.

Table 5. **Radii of section bend obtained in particular simulations**
Tablica 5. **Radijusi koljenastih profila dobivenih posebnim simulacijama**

Variant	$a = \Delta L/L$ 99,5 % Al	AlCuMg
1	0,117254	0,118192
2	0,098480	0,101413
3	0,206390	0,209557
4	0,200104	0,198484
5	– 0,051210	0,005794
6	0,086594	0,020556
7	0,184602	0,189256
8	0,189025	0,191189

To determine the optimal values of the antechamber, for both alloys, the approximation of the function (3) was made and the coefficients $c_{0...123}$ were calculated:

$$f = a = c_0 + c_1X_1 + c_2X_2 + c_3X_3 + \\ + c_1c_2X_1X_2 + c_1c_3X_1X_3 + c_2c_3X_2X_3 + c_1c_2c_3X_1X_2X_3 \quad (3)$$

where:

X_1, X_2, X_3 - absolute values of parameters, corresponding to particular simulations of the process.

The coefficients of the equation (3) are determined with the method of the mean squares.

After substituting the coefficients $c_{0...123}$, equation (3) takes on the following form:

$$f_{99,5\ \%\mathrm{Al}} = 0,128905 - 0,01465 \cdot X_1 - 0,0613 \cdot X_2 + \\ + 0,026652 X_3 - 0,01511 \cdot X_1 X_2 + 0,020911 \cdot X_1 X_3 + \\ + 0,018435 \cdot X_2 X_3 + 0,18234 \cdot X_1 X_2 X_3$$

$$f_{\mathrm{AlCuMg}} = 0,129304 + 0,001396 \cdot X_1 - 0,06782 \cdot X_2 + \\ + 0,027607 X_3 - 0,00089 \cdot X_1 X_2 + 0,005567 \cdot X_1 X_3 + \\ + 0,020706 \cdot X_2 X_3 + 0,002318 \cdot X_1 X_2 X_3$$

where:

$$X = \frac{2(x_i - x_0)}{x_{max} - x_{min}}$$

$$x_0 = \frac{x_{max} + x_{min}}{2}; \qquad x_i = \frac{X(x_{max} - x_{min})}{2} + x_0 \qquad (4)$$

Substituting actual values in place of x_{max}, x_{min} the actual equation coefficients $c_{0...123}$, can be determined, which are given in Table 6.

The obtained equations served for plotting graphs representing the variation of section bend as a function of two variables: the absolute values of antechamber surface area - X_2 and the displacement of the die channel on the die surface - X_3.

Figure 4. shows an example of the variation of bend of the 99,5 % Al section.

For points lying on the red line, the parameter *a* defining the quantitative bend of the section is 0.

Table 6. **Actual values of equation coefficients for the alloys investigated**

Tablica 6. **Stvarne vrijednosti koeficijenata jednadžbe istraživanih slitina**

Coefficient	99,5 % Al	AlCuMg
c_0'	0,078284	0,021308
c_1'	– 0,003900	– 0,004310
c_2'	– 0,00016	– 0,000170
c_3'	0,000186	0,007500
c_{12}'	– 0,000043	0,000005
c_{23}'	– 0,000050	0,000005
c_{13}'	0,000669	0,000813
c_{123}'	0,000006	0,000001

Based on the investigation carried out, the optimal parameters of the antechamber have been determined for the 99,5 %Al alloy, which are as follows: the antechamber height, h = 14,642 mm; and the antechamber surface area, S = 3731,88 mm^2.

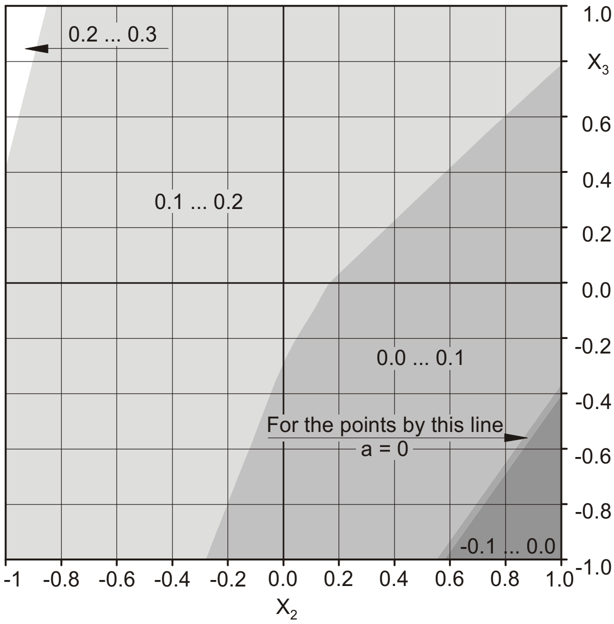

Figure 4. **Dependence of 99,5 % Al section bend on the absolute parameters X_2 and X_3 for X_1 = 1**

Slika 4. **Ovisnost koljenastog profila od 99,5 % o apsolutnim parametrima X_2 i X_3 za X_1 = 1**

CONCLUSIONS

From the performed investigations, it can be concluded that:

1. By using the three-dimensional model of the process of extrusion of T-shaped section, relationships can be obtained, which allow the determination of section bend depending on the geometric parameters of the tool.
2. For the investigated alloys, the minimum section bend was obtained by:
   a) increasing the antechamber height,
   b) bringing the die channel closer to the die centre, and
   c) increasing the antechamber surface area.
3. It is possible to obtain a straight product by using various combinations of die geometrical parameters.

REFERENCES

[1] A. A. Milenin: Matematiczeskoje modelirowanie i reszenie technologiczeskich zadacz pressowania fasonnych profilej, Stal (1999) 8, 57 - 60.

[2] A. Henzel, T. Szpittel: Rasczet energosiłowych parametrow w processach obrabotki metallow dawleniem, Metallurija, 1982, s. 360.