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THE INFLUENCE OF GEOMETRY EXTRUDATE CROSS-SECTION ON MECHANICS OF METAL FLOW IN EXTRUSION

WPŁYW GEOMETRII PRZEKROJU POPRZECZNEGO WYROBU NA MECHANIKĘ PLASTYCZNEGO PŁYNIĘCIA METALU W PROCESIE WYCISKANIA

The paper presents the analysis of nature of metal flow during extrusion of non-circular sections and determining the relationship between extrusion force and geometrical parameters of extrudate (the shape of the extrudate).

Experimental procedure was curried out for the simplest cases of non-circular profiles (triangle, square, rectangular) of various geometrical parameters. The investigations of direct extrusion of lead using set of flat and conical dies have been done under laboratory conditions. The extrusion load and punch displacement have been registered during experimental work.

By determining parameters of metal plastic flow (the depth of plastic zone L_p and the dead zone angle α_{sm}) it has been shown the difference in nature of metal flow during extrusion product differing in non-circular sections. This differentiation results in the complex nature of flow consequential from change with circular section of the billet to non-circular section of extrudate.

It has been shown that flow resistance can be different with regard to appearing configurations of deformation zones (the size and shape of plastic zone, dead and shear zones) and dependent from for example geometrical parameters of a die (shape and size of an die orifice).

It has been shown that identified deformation zone, their description and connection with the shape of extrusion product and extrusion load let modify analytical relationship determining the extrusion load through introduction of the "shape factor". It may improve designing such ones especially for more complicated cases of extrusion of non-circular profiles.

Keywords: extrusion non-circular sections, extrusion load, shape factor, metal flow in extrusion

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W pracy przedstawiono analizę charakteru plastycznego płynięcia metalu podczas wyciskania wyrobów o niekołowym kształcie przekroju poprzecznego oraz określenie wpływu kształtu przekroju poprzecznego wyciskanego wyrobu na wielkość siły wyciskania.

Wyciskanie przeprowadzono dla najprostszych przypadków profili niekołowych (trójkąt, kwadrat, prostokąt) o odpowiednio zróżnicowanych parametrach geometrycznych.

W warunkach laboratoryjnych zrealizowano cykl badań wyciskania współbieżnego ołowiu z zastosowaniem zespołu dzielonych matryc płaskich i stożkowych. Podczas eksperymentu rejestrowano siłę wyciskania oraz przemieszczenie.

Poprzez określenie parametrów strefy plastycznego płynięcia (głębokość strefy plastycznej L_p, kąt strefy martwej α_{sm}) pokazano różnice w charakterze płynięcia metalu podczas wyciskania wyrobów o różnym kształcie przekroju poprzecznego, wynikające głównie ze złożonego charakteru płynięcia przy przejściu z przekroju kołowego wlewka na przekrój niekołowy wyrobu.

Wykazano również, że opory płynięcia są różne w zależności od powstającej konfiguracji stref odkształcenia (wielkość i kształt strefy plastycznej, martwej i strefy ścinania) i zależne m. in. od parametrów geometrycznych matrycy (kształt i wielkość oczka matrycy).

Identyfikacja stref odkształcenia oraz ich powiązanie z kształtem przekroju poprzecznego wyciskanego wyrobu i siłą wyciskania stanowi podstawę modyfikacji zależności określających wielkość siły wyciskania poprzez uwzględnienie czynnika kształtu i właściwego sformułowania wytycznych do projektowania procesu wyciskania wyrobów o złożonym kształcie.

1. Introduction

The possibility to obtain products of different shapes mainly from aluminium and aluminium alloys, e. g. in the aspect of complexity of the shape and thin-walled sections are difficult to determine with regard on insufficiently examined processes of deformation as well as the side of description of mechanical behaviour of the material (the change of structure and properties) and the technology (the selection and controlling the parameters of process). For years this alloys mainly in aerospace, packing and building constructions industries taking advantage of their lightweight, high ductility combined with good corrosion resistance. Since the late eighties aluminium alloys and the manufacturing processes employed to form them into final shapes have been redesigned significantly. Today they need to manufacture engineered product with higher physical characteristics than those architecture and construction industry but for a fraction of the cost of those used in the aerospace industry. The ultimate goal to equip the process designers with such tools to allow them designing processes that are lower in cost and produce aluminium product with improved material characteristics.

The wide use as well as production of shapes about with complex cross-sections (Fig. 1) creates the need conduct researches to make investigations including the analysis of structure of the material as well as its transformation in different temperature — velocity — force conditions.

One of basic criteria to evaluate possibilities of forming in the process of plastic work are the amount of quantify of pressures and their distribution on contact surface from tool [1÷9].

Many factors influence on the magnitude of unit pressure. We can include the following:

- the properties of materials (physical, chemical, structure)
- the kinematics of movement of tools and of the material (the kind of extrusion process: direct and indirect extrusion)
- magnitude of relative strain and uniformity of their distribution
- shape and dimensions of final material
- friction conditions
- shape, dimensions and quality of work surface of elements of the tools (dies, punch)
- temperature and heat balance of the process
- strain rate.

Fig. 1. The examples of modern production of complex extrudates

The extrusion force results in resistance of deformation of extrusion metal while being total effect of plastic resistance and flow resistance. The flow resistance can be different with regard to appearing configurations of deformation zones (the size and shape of plastic zone, dead and shear zones). The flow resistance dependent from for example geometrical parameters of a die (shape and size of an orifice die, height of bearing area).

The differentiation in size and shape of deformation in dependence on the shape of extrudate cross-section and extrusion load is especially visible in the case of extrusion of non- axisymmetrical sections. This differentiation results in the complex nature of flow consequential from change with circular section of the billet on non-circular section of extrudate and various configuration of deformation zones (the size, shape and volume of plastic zone) to comparison with extrusion of axi- symmetrical cross-section extrudate (Fig. 2).

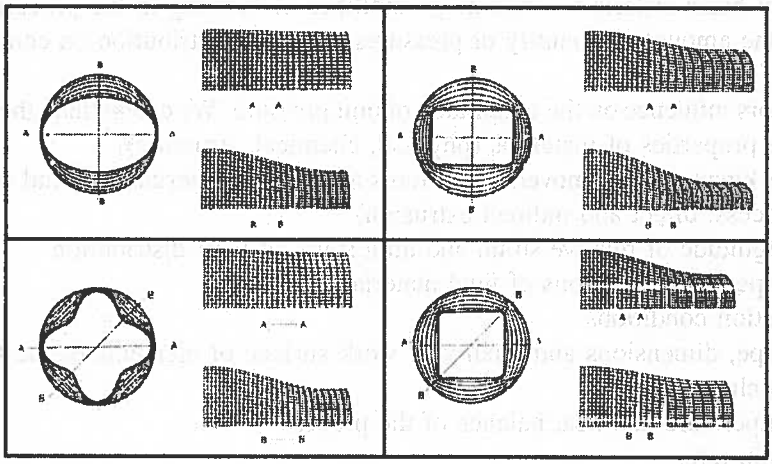


Fig. 2. Character of plastic flow in the case of extrusion of non- axisymmetrical sections [10]

The professional literature provides but little information about effect of geometry of cross- section extrudate on mechanics of metal flow and extrusion load [10, 17÷20]. In a lot of works several formulas for calculating the extrusion load have been presented [for example 1÷7]. But there is a lack of relationship in literature for calculation of the extrusion load for non-symmetrical sections. In the case of extrusion of non-circular sections the theoretical evaluations of load a. n. different formulas are considerably different from values assigned experimentally [11]. That is way an additional and a very important factor influencing on level of extrusion load is the size and shape of cross-section extrudate.

Considering the present state of research in this field [12÷16] we can say that in none of the researches studies so far any attempt has been made of an analytical approach to the problem of connecting the of nature of metal flow during extrusion of non-circular sections with the extrusion load. Limited attempts have been found to describe the relationship between the force characteristics of extrusion and of the nature of metal flow (geometrical parameters of plastic and dead metal zones). Evaluation of different mechanical behaviour of deformed material depended on shape and size of the cross-section of extrudate let to determine the relationship between extrusion force and geometrical parameters of product. Description of the type of complex flow (experimental investigations, modelling the process) let to determine proper parameters of the process.

This work contains the results of experimental method of investigation of the character of metal plastic flow during extrusion of non-circular profiles. Results obtained will be used to modification of relationship that lets to calculate the extrusion load through introduction of the factor which determines dependence between extrusion load and the cross-sections of extrudate shape.

2. Experimental work

The aim of the experimental work is analysis of nature of metal flow during extrusion of non- circular sections and determining the relationship between extrusion force and geometrical parameters of extrudate.

Experiments were carried out at room temperature, the extrusion load and punch displacement have been recorded simultaneously.

The experimental part of the study was carried out on a specially equipment, which allowed direct extrusion of metal (Fig. 3).

The material was extruded directly with the use of sectional flat and conical dies (Fig. 4).

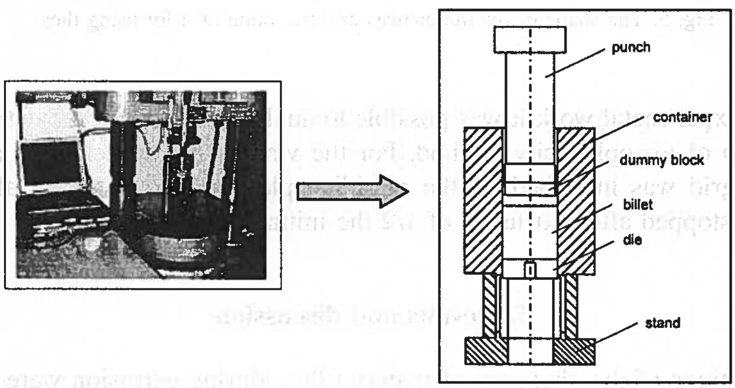


Fig. 3. Scheme of experimental equipment

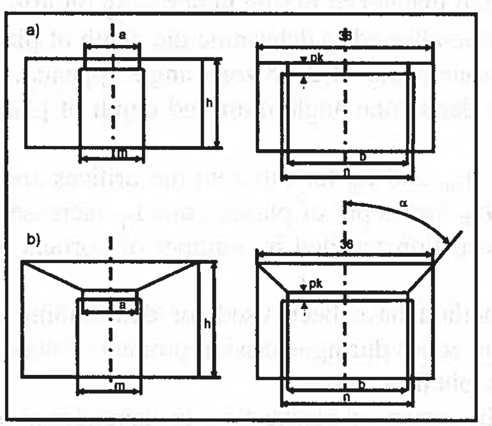
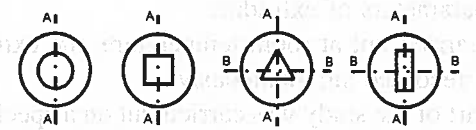


Fig. 4. Scheme of dies: a) flat die, b) conical die

The shape of the die orifices and the value of the used extrusion ratios λ have been presented in fig. 5.

The examined material were Pb 99,98 lead billets of a 36 mm diameter and 72 mm



Shape of the die orifices	λ (extrusion ratio)
circular	3, 12, 60
square	3, 12
triangle	3, 12
rectangle	3, 12, 60

Fig. 5. The shape of the die orifices and the value of λ for using dies

in length.

During experimetal work it was possible to analyse the flow of the extruded metal with the help of visioplasticity method. For the visioplasticity technique a 1,5 × 1,5 mm square grid was inscribed on the meridian plane of the billet. In all cases the process was stopped after extrusion of 1/2 the initial billet length.

3. Results and discussion

Investigations of the character of material flow during extrusion were carried out using visioplasticity method. Grid deformation in cross-section of the billet during extrusion of non- circular sections have been presented in figure 6.

Analysis of the indicated manner of plastic flow basing on grid distortion (Fig.6) have supplied data, which have allowed to determine the depth of plastic zone its shape and the value of the dead zone angle (if dead zone angle appears).

Description of the dead zone angle αsm and depth of plastic zone L_p have been presented in figure 7.

Various values of the α_{sm} and L_p for different die orifices are illustrated in figure 8. The dead zone angle α_{sm} and depth of plastic zone L_p increases with nonregularity of the shape of the cross-section meaned by number of corners or number of axis and plane of symmetry.

The visioplasticity method have been used for determining nature of plastic flow and symmetry of plastic zones during extrusion product of non-circular cross-sections. Figures 9 and 10 show obtained results.

Main differences in the nature of plastic flow in dependence of the shape of the die orifices have been presented in figure 9 and 10. The manner of flow effect on mean pressure and (total) extrusion load. From this point of view it is important to analyse

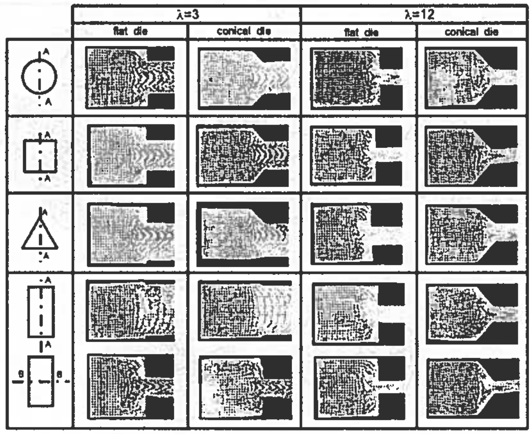


Fig. 6. Grid distortion in the cross-sections of the billet during extrusion of non-circular sections

the characteristic parameters of flow suchlike: shape and a volume of plastic zone, plane and axis symmetry, number of corners of cross-section shape etc. In the case

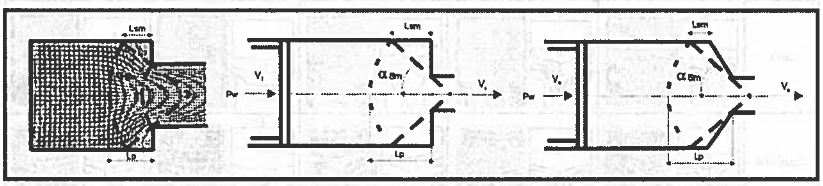


Fig. 7. Description of the values: α_{sm}, L_p dealing with deformation and dead zones

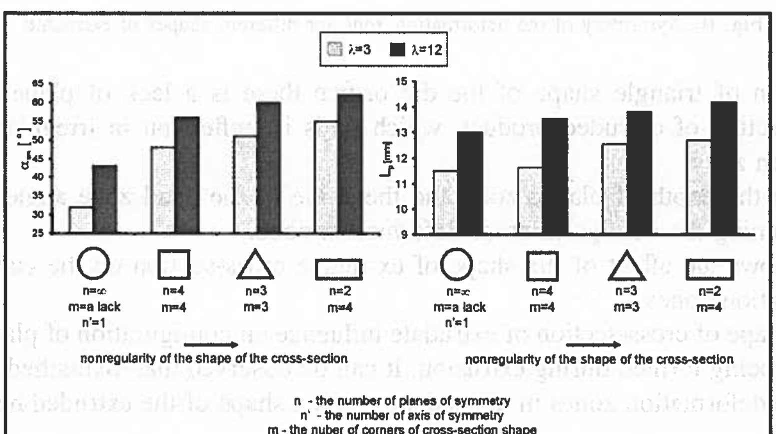


Fig. 8. Comparison of value of the depth of plastic zone L_p and the dead zone angle α_{sm} for different shape of die orifice

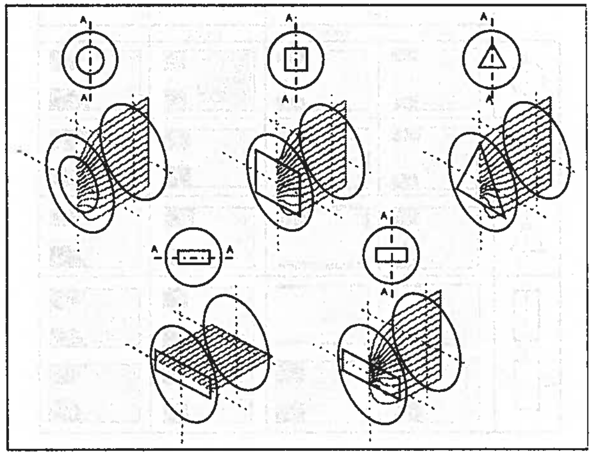


Fig. 9. Comparison of type of metal flow during extrusion of circular and non-circular sections

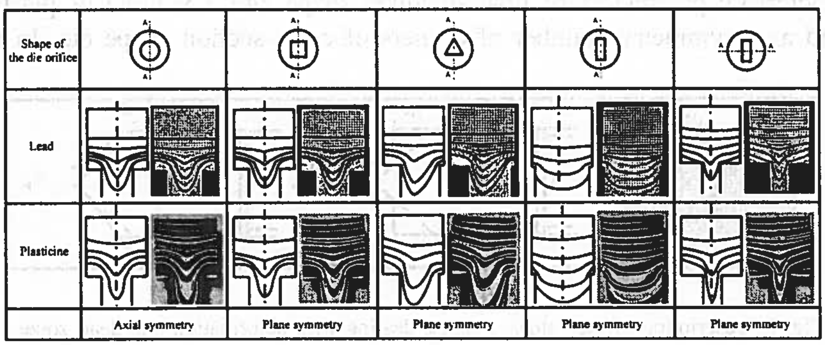


Fig. 10. Symmetry of the deformation zone for different shapes of extrudate

of extrusion of triangle shape of the die orifice there is a lack of plane symmetry in cross-section of extruded product, which finds its reflection in irregular shape of deformation zone.

Determing the depth of plastic zone and the value of the dead zone angle permitted for determining the configuration of deformation zone.

Fig. 11 shows the effect of the shape of extrudate cross-section on the configuration of deformation zones.

The shape of cross-section of extrudate influence on configuration of plastic zones, which are being formed during extrusion. It can be observed that diversified shape and size of the deformation zones in dependence on the shape of the extruded non-circular sections.

On the basis of the change of position of the node of coordination grid obtained distribution of particle velocity in the die region (Fig. 12). Depending on the shape of the cross-section of extrudate obtained different value of the particle velocity; in

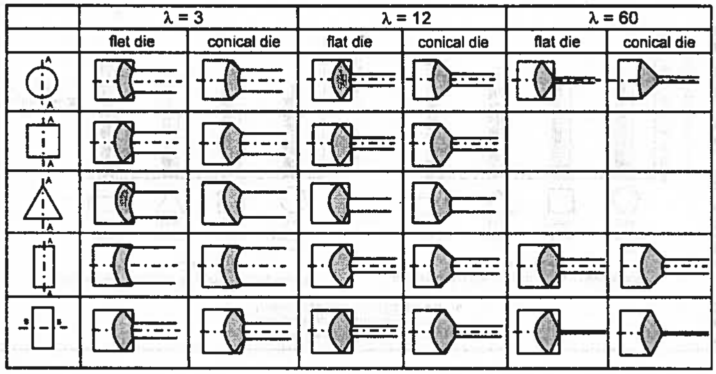


Fig. 11. Configuration of plastic zones during extrusion of circular and non-circular sections

the case of the extrusion of triangle cross-section product there is a lack of symmetry in velocity distribution. The relationship between maximum extrusion load for

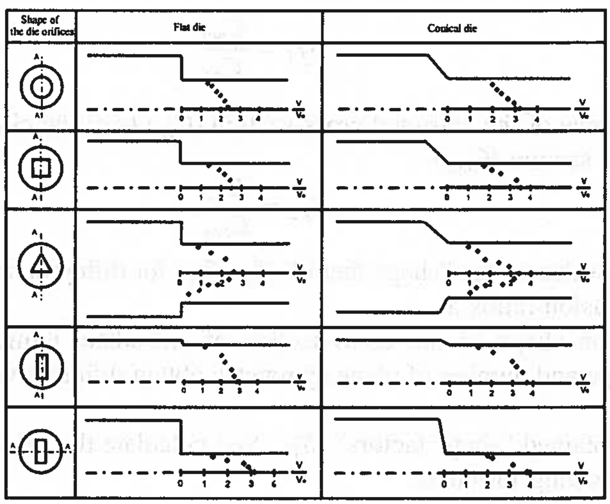


Fig. 12. Distribution of particle velocity in the die region

different extrusion ratio and different shape of extrudate is presented in figure 13. The consequence of formed configuration of plastic zones is the answer in a form of differential size of extrusion load in the case of extrusion different shapes at the same value λ. Furthermore, in case of non-circular sections shape and size of cross-section extrudate significantly influences on quantity of extrusion load, but none of introduced relationships for calculating of extrusion load does not contain an additional factor, which maybe called "shape factor".

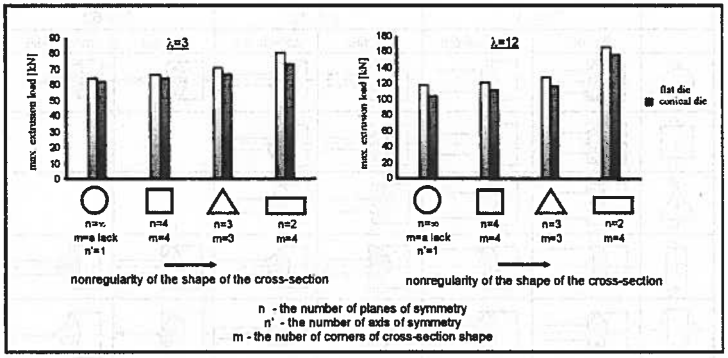


Fig. 13. Comparison of maximum extrusion load for different shape of die orifices

An example parameters which maybe defined as a "shape factor" S_f are proposed:

a) circumference of the non-circular extruded cross-section (C_{ncs}) to circumference of a circle that has the same cross-sectional area as the extruded section (C_{cs})

$$S_{f1} = \frac{C_{ncs}}{C_{cs}}$$

b) circumference of the extruded cross-section (C_{es}) to circle circumscribed about a extruded section (C_{ces})

$$S_{f2} = \frac{C_{es}}{C_{ces}}.$$

Fig. 14 shows the value of the "shape factor" (S_{f1}, S_{f2}) for different shapes of extrudate and different extrusion ratios λ.

In dependence on shape of the cross-section of extrudate, number of corners of cross-section shape and number of plane symmetry obtain different value of the "shape factors".

On the basis of obtained "shape factors" (S_{f1}, S_{f2}) calculate the value of the extrusion load from the following formulas:

$$F = F_1^* S_{f(n)}, \tag{1}$$

where: F — extrusion load of non-circular profiles

F_1 — extrusion load of round bar

$S_{f(n)}$ — "shape factor".

The extrusion load of round bar was calculated with the following relationships:

1) Siebel $F = A_0 k_w \ln \lambda$ (2)

2) Eisbein $F = k_w A_0[(\ln \lambda + 1)e^{\frac{4\mu L}{D_p}} - 1]$ (3)

3) Gubkin $F = k_w A_0[(\ln \lambda + e^{\frac{4\mu L_p}{d_m}})e^{\frac{4\mu(L-a)}{D_p}} - 1]$ (4),

where: A_0 — cross sectional area of the container, k_w — flow stress, λ — extrusion ratio, μ — coefficient of friction, L — length of the extruded product, D_p — container

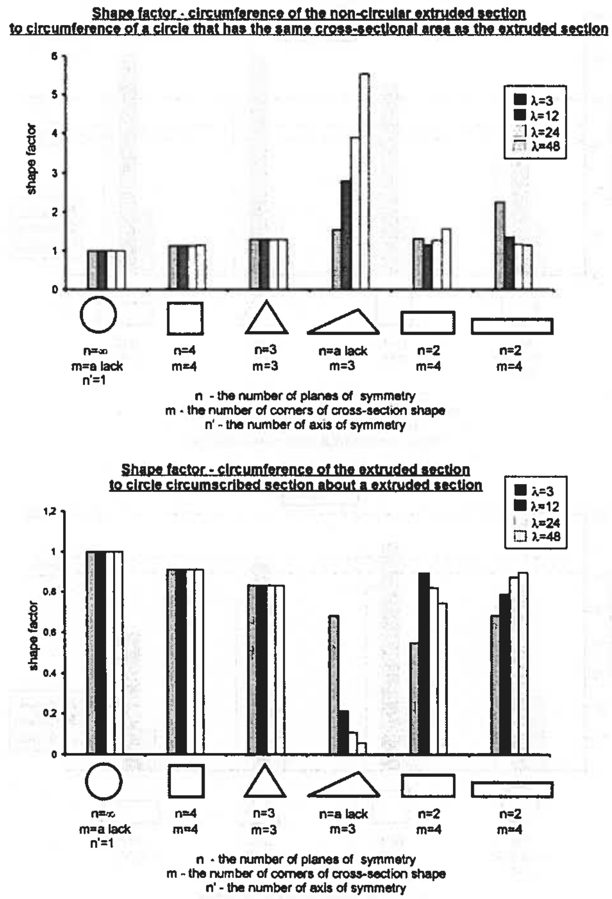


Fig. 14. The value of the "shape factor" (S_{f1}, S_{f2}) for different shapes of extrudate

diameter, L_p — length of the bearing area, d_m — diameter of the extruded product, a — the height of the dead zone.

The value of calculated extrusion load [with formulas (1)] for the following shapes of extrudate: equilateral triangle, square, rectangle have been presented in fig. 15.

The theoretical evaluations are different from values assigned experimentally. Parameters of shape of extruded products (e.g. number of corners, acute and obtuse angles in extruded shape, number of axes and planes of symmetry, ratio of maximum to minimum thickness of walls of segments of profiles cross-sections) effect of extrusion load in different degree. Singling out of most important parameters of shape effecting of extrusion load and determination of relationship between them suggesting of shape factor which modifying analytical formulas defining load forming.

The aim of the continue investigations will be modification of a/m "shape factors" and introduction their to relationship for calculating of extrusion load of non-circular sections.

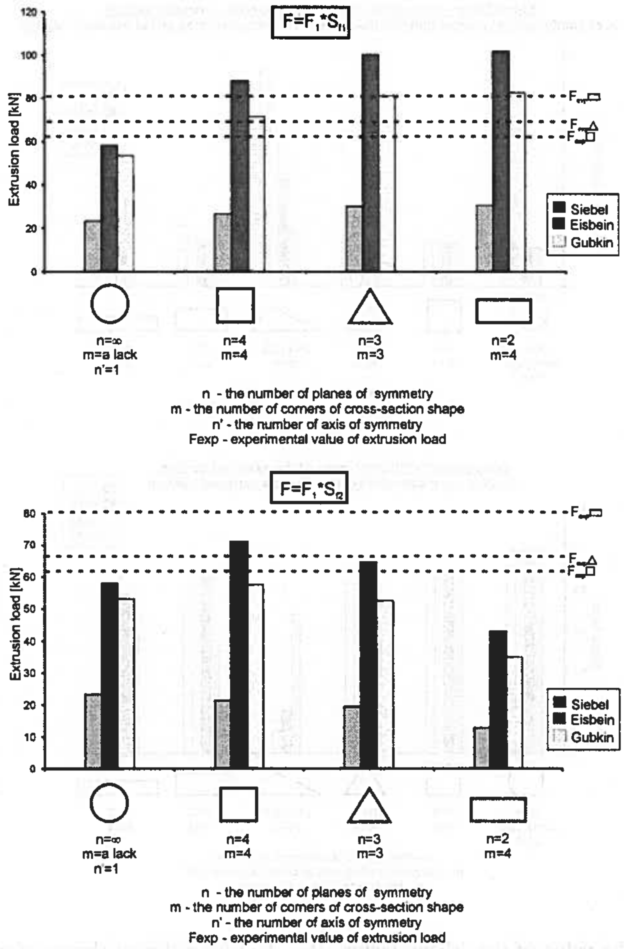


Fig. 15. Comparison of theoretical and experimental value of the extrusion load of non-circular section ($\lambda = 3$)

4. Conclusions

Based on the results in this study, the following can be concluded.

1. By determining parameters of metal plastic flow (the depth of plastic zone L_p, the height of the dead zone L_{sm}, the value of dead zone angle α_{sm}) it has been shown the difference in nature of metal flow during extrusion product differing in non-circular sections. Parameters of metal plastic flow determine the shape and the region (volume) of plastic zone, which influences on the extrusion load directly.
2. Shape complexity significantly influences on the extrusion load. The extrusion load is the lowest for the circular cross-section; it increases for the square, triangle and rectangle cross-sections respectively. The attribute which determines the

shape of the extruded cross- section (e.g. number of corners, acute and obtuse angles in extruded shape, number of axes and planes of symmetry, thickness of walls of segments of profiles cross-sections) reflect in the influence of shape extruded on size of extrusion load.

3. The identified deformation zone, their description and connection with the shape of extrusion product and extrusion load let to modify analytical relationship determining the extrusion load through introducing the "shape factor". It may improve designing such ones especially for more complicated cases of extrusion of non-circular profiles.

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