G. RYZIŃSKA, R. ŚLIWA

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THE THEORETICAL AND EXPERIMENTAL RESEARCHES OF PB-AL COMPOSITE MATERIALS EXTRUSION

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The work presents the analysis of the character of a simultaneous plastic flow of composite material of a hard core-soft sleeve structure. Experimental research work using model composite material Aluminium-Lead and theoretical analysis allowed to identify the initial cracking conditions, its character and localization, depending on geometrical parameters of the composite materials and the extrusion ratio value. It has been shown that the higher the parameters' values are, the longer the flawless extruded product is (cracking appears in the further stages of the process).

Key words: extrusion, composite Pb - Al, fracture of composite, plastic flow

Teorijska i eksperimentalna istraživanja ekstruzije Pb-Al kompozitnog materijala. Članak daje analize karaktera simultane ojačane jezgre i mekše vanjske strukture. Eksperiment je rabio model kompozitnog materijala olovo-aluminij a teorijske analize omogućavaju utvrditi uvjete početnih pukotina, njihov karakter i lokalizaciju, ovisno o geometrijskim parametrima kompozitnih materijala i veličine ekstruzije. Ustrojene su maksimalni parametri vrijednosti ekstruzije bez pojave pukotina (napukline se pojavljuju u idućim stadijima procesa)

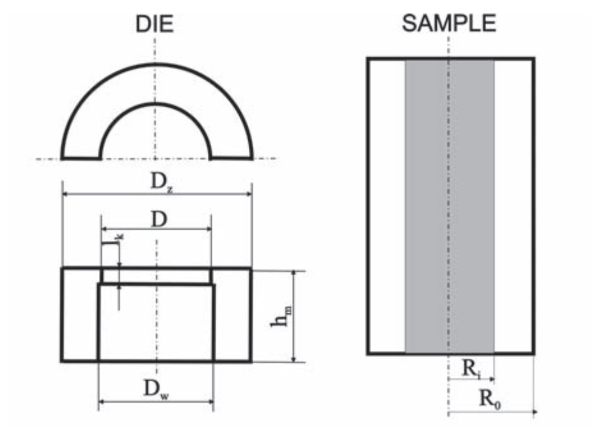
Ključne riječi: ekstruzija, kompozit Pb-Al, prijelom kompozita, krivulja plastičnosti

INTRODUCTION

A fracture phenomenon is a basic factor reducing the material ductility while plastic processing it. Finding out the conditions conducing fracture in given process conditions allows to indicate the method of avoiding the fracture. This problem is of particular importance in the analysis of more complex processes, e.g. simultaneous plastic extrusion of materials of different properties in order to obtain composite material of expected properties [1-3]. The extrusion process of core-sleeve composite materials, such as rods, bars or wire, makes it necessary to search for the possibility of an appropriate core- or sleeve- fracture prognostication. In the simultaneous extrusion process of materials having different properties, deal with diverse component ductility, which cannot be entirely leveled by matching the process parameters because the components' values are so different [4– 6].

EXPERIMENTAL RESEARCH

Test extrusions, with the use of composite metallic materials, were carried out at a test bench consisting of a hydraulic press equipped with force sensors, ram displacement sensors, a set of tools and a measurement and recording system. A complete set of dies included flat dies to obtain three different reduction degrees of extrusion ratio λ (see Figure 1). The research of the metallic composite extrusion concurrent process was conducted with the use of two-ply samples. The test samples had the form of a core (Al) with a concentric sleeve (Pb). Outer dimensions of the sample are: D_0 =36mm, h=72 mm (fastening between core and sleeve -interference fit). Seven kinds of complex extrusion samples have been prepared (Figure 1).



Parameter	Value
R_i/R_0	0,17; 0,22; 0,28; 0,33; 0,39; 0,44; 0,50
D_z / mm	36
D / mm	20,78; 14,70; 10,38
h_m / mm	20
l_k / mm	2
$\lambda = D_z^2/D^2$	3; 6;12

Figure 1 Geometric arrangement of the dies and samples

G. Ryzińska, R. Śliwa, Rzeszow University of Technology, Rzeszow, Poland

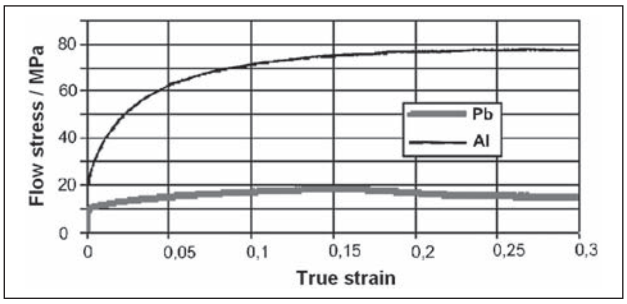


Figure 2 Stress – strain curves for researched materials indicated in uppsetting test of different geometric parameters samples

Dependence between flow stress and true strain for both materials used in research are shown in Figure 2.

Prior to the extrusion process, the samples were cleaned and sterilized with acetone. In this way, it was possible to determine comparable friction conditions between a container and a batch for all kinds of samples.

EXPERIMENTAL RESULTS

After the extrusion process was completed, the obtained results were presented in the form of a force versus ram displacement plot. As a result of complex billet extrusion, various products were obtained, which were further cut along their axis in order to enable the observation of inner processes. Exemplary results are shown in Figures 3 to 5. Visible core fracture is caused by the difference between plastic flow speeds of individual composite elements, and a result of which is exceeding acceptable tensile stress of the core material. Performed experimental results of composite material extrusion enabled to determine the beginning of fracture for all examined specimen's geometrical variants depending on the die used, which determined the reduction level of cross section, and also characteristics and information on possible core fracture in the composite being extruded. The results were composed in tabular form (Table 1).

The achieved cross section image correlation of extruded product along with the ram displacement course enables to evaluate:

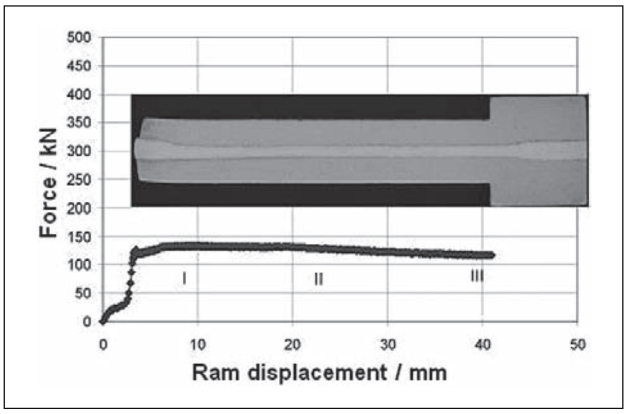


Figure 3 Force – ram displacement curve. Extrusion of composite Pb-Al, R_i/R_o=0,17 λ=3

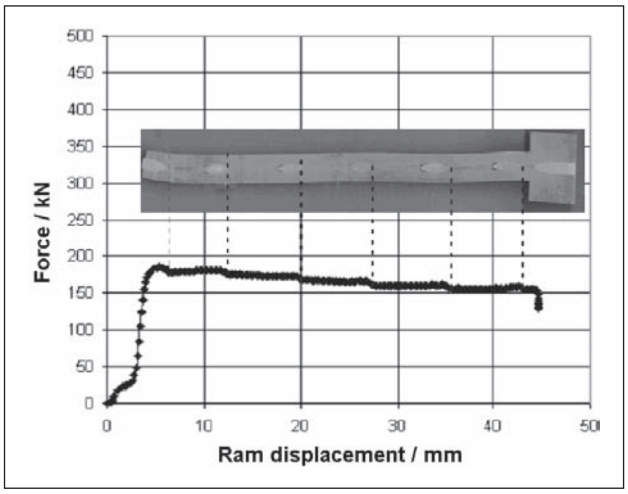


Figure 4 Force – ram displacement curve. Extrusion of composite Pb-Al, R_i/R_o=0,17 λ=6

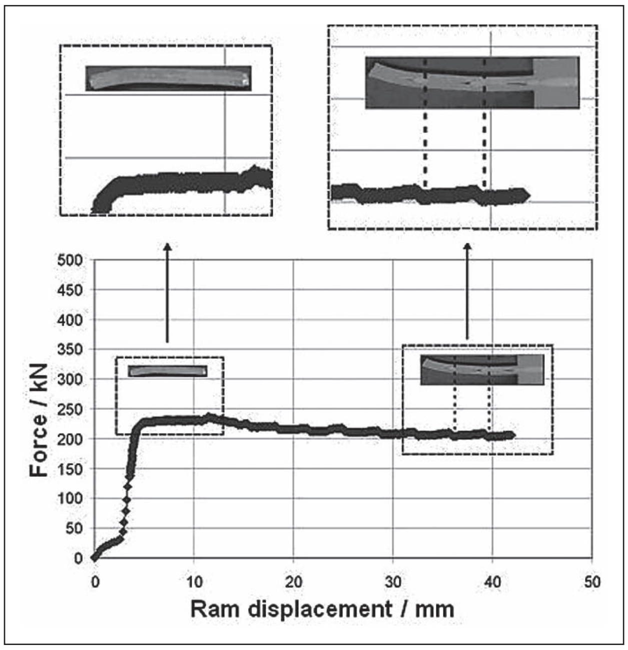


Figure 5 Force – ram displacement curve. Extrusion of composite Pb-Al, R_i/R_o=0,17, λ=12

- the phenomenon of fracture periodicity,
- the values of relevant parameters (a, b, c, d, α ,β, γ c', e, f, F_H-F_L), which describe the fracture effect (Figure 6).

The experiment revealed that the fracture occurred in average once the 10 % of initial sample length is extruded. The core fracture was not observed in products made with the die of an extrusion ratio λ=3. Based on extruded and cross cut longitudinally composite specimens, the following length measurements were performed: an initial length of core part (a), core fragment length (b) and the distances between them (c, d). The images of the composite samples, extruded and cut along the axis, were compared with the extrusion force versus ram displacement diagrams for individual samples. As a result, a correlation was obtained between parameters describing individual dimensions of the core fragments and the distances between them (a, b, c, d)

Table 1 **Fracture in experimental research. Relative length of extruded sample for beginning of fracture depending on extrusion ratio λ and geometric arrangement of samples**

λ	R_i/R_o	Relative length of extruded sample /%
3	0,17	-
3	0,22	-
3	0,28	-
3	0,33	-
3	0,39	-
3	0,44	-
3	0,5	-
6	0,17	8,70
6	0,22	10,09
6	0,28	11,55
6	0,33	11,09
6	0,39	11,59
6	0,44	11,59
6	0,5	9,88
12	0,17	17,8
12	0,22	6,88
12	0,28	7,77
12	0,33	7,95
12	0,39	8,10
12	0,44	5,24
12	0,5	10,49

with the corresponding parameters presented on the extrusion plot (e, f ,c', F_H-F_L). Next, the parameters measurements were performed, as presented in Figure 6. The measurements were made on a real object, the measurements on graphs were made proportionally in X and Y direction.

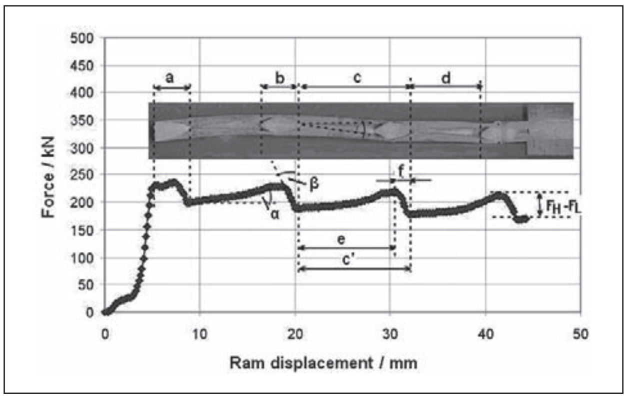


Figure 6 Scheme of the measurement procedure of the distances between the split core parts, dimensions of the core elements a, b, c, d, and the corresponding distances in the extrusion plot e, f, c', F_H-F_L

The parameters *b, c, d* clearly increase along with R_i/R_o value increase, in contrary to parameter a (λ=12), which decreases along with R_i/R_o value increase. For the lowest R_i/R_o values the highest values of this parameter were achieved (Figure 7).

Measured extrusion force drops for core fracture in the composite vs. R_i/R_o value reveal that F_H-F_L value

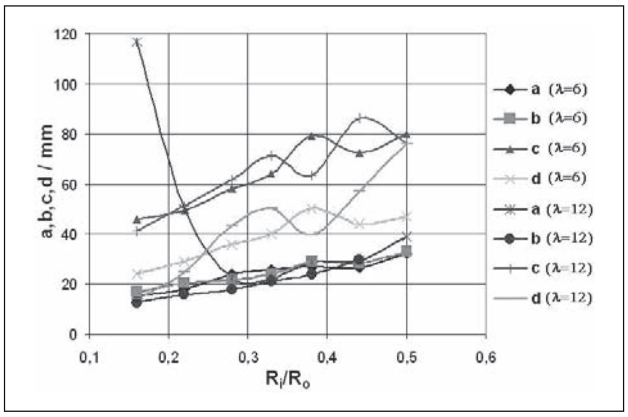


Figure 7 Dependence between a,b,c,d parameters and R_i/R_o ratio (λ=6, λ=12)

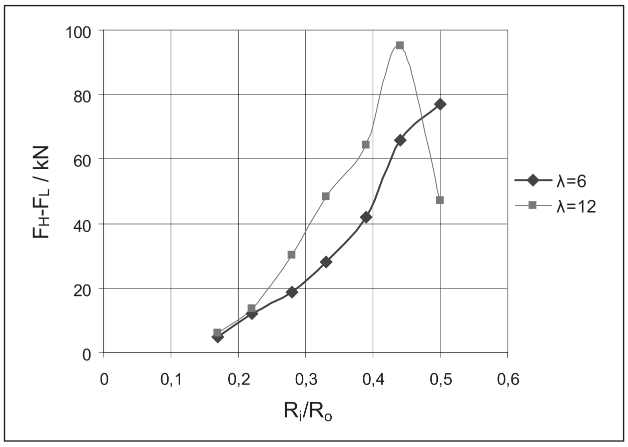


Figure 8 Dependence between F_H-F_L and R_i/R_o ratio (λ=6, λ=12)

(Figure 8) increases along with the core volume ratio expressed as R_i/R_o value.

The c', e, f parameters measurements performed based on extrusion force vs. ram displacement diagram enable to plot the relation of these parameters on the core volume ratio in composite (Figures 9 and 10) expressed as R_i/R_o value. Achieved maximum values of parameters c' and e overlap D/D_w value (presented as a dashed line on figure). The parameter f has an increasing trend.

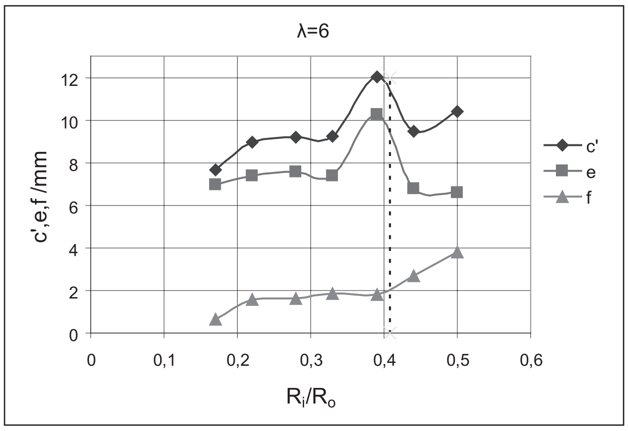


Figure 9 Dependence between c', e, f parameters and R_i/R_o ratio (λ=6)

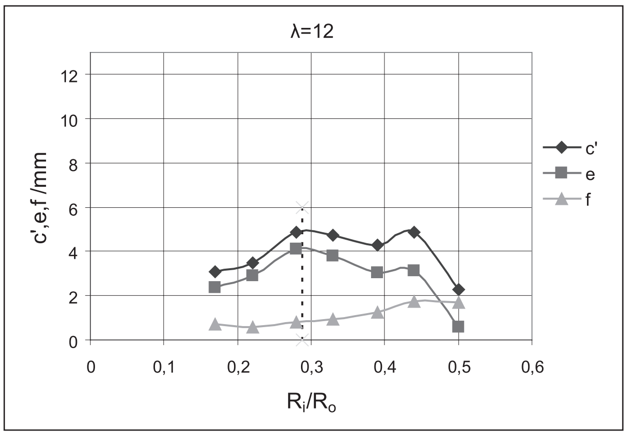


Figure 10 Dependence between c', e, f parameters and R_i/R_o ratio (λ=12)

Corresponding angles on specimens (α and β - see Figure 6) and on extrusion force vs. ram displacement diagram (γ) were measured and related to R_i/R_o value. These relations were presented on Figure 11. The explicit increasing trend of α angle along with R_i/R_o ratio increase and decreasing trend of β angle were observed. The values of γ angle are not changing.

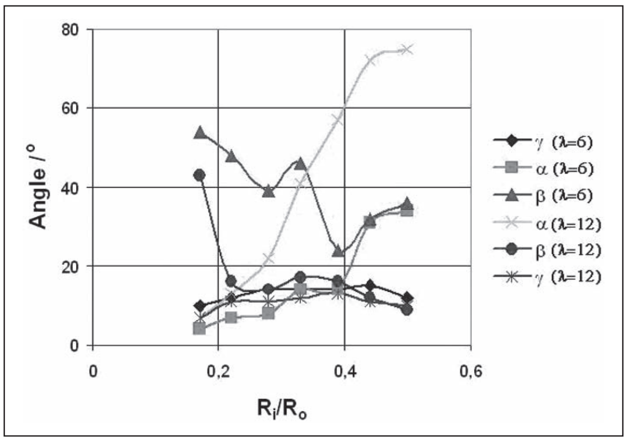


Figure 11 Dependence between α, β, γ angles and R_i/R_o ratio (λ=6, λ=12)

The researches on composite specimen extrusion revealed force vs. ram displacement data. The experiment performed revealed certain data on beginning of fracture (Table 1) for all examined specimen geometrical variants depending on die used, which determines the reduction level of cross section. Data on characteristics and location of possible core fracture in the composite being extruded were also achieved. It was revealed that the fracture occurred in average once the 10% of initial length of sample is extruded. The used die of extrusion ratio λ=3 allowed to deliver products without core fracture. For other cases, the core fracturing in products was observed. Achieved characteristics of force vs. ram displacement enabled also, comparing to longitudinal section images of products, to gain the correlation between distinctive points of diagram and their image in form of corresponding product parts (Figure 6). Based on extruded and cross cut longitudinally products, the following length measurements were performed: an initial length of core part, core fragment length and the distances between them, relating these values to R_i/R_o parameter value. The relation of parameters a, b, c, d – measurements performed on specimen – to R_i/R_o value (the measure of core volume ratio in composite material) was achieved, which were compared against corresponding parameters measured on an extrusion diagram (e, f, c', F_H-F_L). Gained characteristics of parameter relations (b, c, d) has an increasing trend. The length of individual core fragments in composite increases along with increasing core volume ratio, thus increases also the distance between these fragments.

The function F_H-F_L (R_i/R_o) has an increasing trend. This means that an increase of core volume ratio causes an increase of core forming ratio comparing to extrusion force.

The c', e, f parameter measurements performed based on extrusion force vs. ram displacement diagram enabled to plot the relation of these parameters on R_i/R_o value. Achieved relation reveals the maximum (for parameters c', e), which exists for R_i/R_o value convergent to D/D_w value. This means that c' and e parameter value increases in a stepped way for the core diameter convergent to the die orifice, and then further decreases.

Measurements of corresponding angles on each specimen enabled to plot charts depicting the relation of these parameters vs. core volume ratio in the composite. The increasing trend of α angle and decreasing trend of β angle were observed. Along with R_i/R_o value increase, γ angle value stays almost unchanged. The α angle increase is combined with F_H-F_L value. The lower the forming force of entire composite (the sleeve and core) and the sleeve, the higher α angle. High β angle indicates slow core separation.

CONCLUSIONS

The analysis of the character of a simultaneous plastic flow of composite material of a hard core- soft sleeve structure allowed to identify the initial cracking conditions, its character and localization, depending on geometrical parameters of the composite materials, and the elongation ratio value. It was proved that the higher the parameters' values are, the longer the flawless extruded product is (cracking appears in the further stages of the process). The results of this work may substantially improve the modeling of layered composite extrusion processes.

The characterizations of the force curve in the ram displacement function in comparison with the corresponding images of the longitudinal cross-sections of the extruded products allowed for the correlation of the characteristic points in the extrusion plots and their images in the form of the corresponding product parts. Introduced parameters: a, b, c, d, c', e, f, F_H-F_L (a, b, c, d – values determined experimentally on the extruded product, c', e, f, F_H-F_L – values in the extrusion plot) allow for an adequate description of the cracking core phenomenon in the extruded composite material.

It was proved that there is a characteristic disturbance in the composite material flow, which results in the tendency to change parameters (c', e) as presented in the extrusion plot. The obtained dependence of parameters c' and e on the R_i/R_o values shows the maximum which occurs for the R_i/R_o value, concurrent with D/D_w value. It shows there is a correlation between the way the composite flows and the batch geometry, in relation to the die opening's dimension.

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Note: The responsible translator for English language is Grzegorz Rembisz; Rzeszow, Poland