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APPLICATION OF THE CONVEX DIE DURING EXTRUSION OF THE BI-MATERIAL

In this work experimental studies of metal flow in the co-extrusion of two different materials of core-sleeve system have been presented. The influence of the initial billet geometry (components arrangement and volume ratios) of core-sleeve system (using soft lead, hard lead alloy as model materials and set of the convex dies) on final effect of simultaneous deformation of layered composite has been investigated. Basing on the analysis of the grid distortion, range of the deformation zones, extrusion load and relative velocity distribution in the plastic zone and orifice region, the best convex die geometry in comparison with others has been proposed. It can be selected taking into account relatively small plastic zone, more uniform deformation and relatively small extrusion load. Based on the experimental study of the extrusion load using convex dies, the dependence of maximal load on the angle of the die have been determined.

Keywords: extrusion, convex die, composite materials

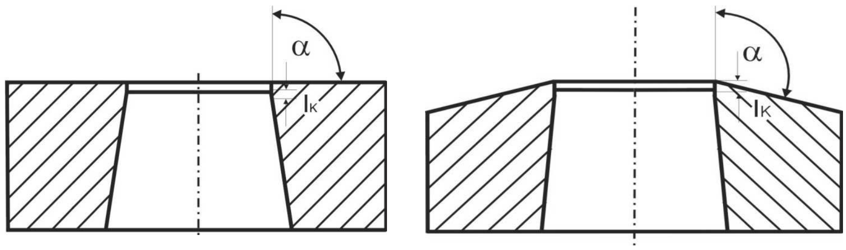
Introduction

One of the important advantages of extrusion process is that the final shape of the product can be obtained in a single operation with large change of shape and there is possibility of influencing the deformation zone by changing the shape of the die. Material flow during extrusion process strongly depends on the die design. Choice of adequate die geometry guarantees controlling metal flow under conditions of plastic deformation. Traditional dies for extrusion of bars and rods are conical dies and flat face dies. In case of the extrusion of layered composite (e.g. of sleeve – core system) type of flow of the core and the sleeve can be completely different. It is necessary to be able to determine the conditions for sound flow, which is more complicated in the forward extrusion of various metals in comparison with monomaterial extrusion [1÷4]. Basing on the results of the experimental works the flow of single material in extrusion using a convex die it has been found that such tool may cause better, more regular flow [5÷6]. The use of the convex die gives a possibility to obtain advantageous change of the character of layered composite flow in the plastic zone and increase of extrudate velocity in the orifice of the die.

Experimental procedure

The experiments were performed on a vertical hydraulic press. A set of flat and convex dies leading to the various extrusion ratios ($\lambda = 3$, $\lambda = 12$) were used in forward extrusion without lubrication (Fig. 1). Composite material consisting of the following materials: soft lead and hard lead has been used for testing. Selected features of materials used for testing are presented in Table 1. Composite billets have been prepared in concentric layout: core with circular section – sleeve in hard core-soft sleeve configuration and vice versa with various volumetric fraction of the core: $V_{core}/V_{composite} = 0.08$, $V_{core}/V_{composite} = 0.31$ and $V_{core}/V_{composite} = 0.60$ (Fig. 2). Basic parameters of performed extrusion tests are presented in Table 2.

a) b)



α = 90° α = 95°, α = 100° and α = 105°

Fig. 1. Flat die (a) and convex die (b) used in the extrusion process
Rys. 1. Matryca płaska (a) oraz wypukła (b) stosowane w procesie wyciskania

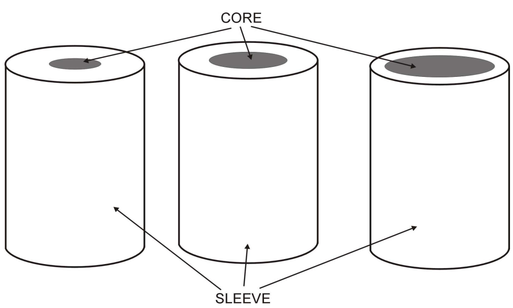


Fig. 2. The view of the billet of core-sleeve system with various volume fractions of the components
Rys. 2. Widok próbek typu rdzeń-powłoka z różnym udziałem objętościowym komponentów

Material characteristics describing relationship between stress σ and true strain ε for soft lead and hard lead (Fig. 3) have been determined based on uniaxial compression test. The extrusion load has been measured to confirm the best mode of composite flow. Investigations of the flow during extrusion were carried out using grid distortion method. In all cases the process was stopped after 50% of the initial billet length was extruded. After extrusion billets were pushed out of the container and split. The grid distortion was recorded and analyzed.

Table 1. Some features of materials used in investigations
Tabela 1. Charakterystyka materiałów stosowanych w badaniach

Material	**Chemical composition [%]**	**Yield stress [MPa]**	**Brinell Hardness [HB]**
Hard lead	2.5-3.5 Sb; 0.015 As; 0.04 Cu; 0.012 Fe; 0.01 Bi	10	8.7
Soft lead	99.98 Pb; 0.002 Ag; 0.001 As; 0.001 Sb; 0.001Sn; 0.002 Cu; 0.002 Fe; 0.001 Zn; 0.005 Bi	5	5.3

Table 2. Process parameters used in experimental work
Tabela 2. Parametry procesu stosowane w eksperymencie

Parameter	**Unit**	**Value**
Temperature of extrusion	ºC	20
Billet diameter	mm	36
Billet height	mm	72
Extrusion ratio $\lambda = D_0^2/d^2$ (D_0 – diameter of billet, d – diameter after extrusion)	-	**3; 12**
Extrusion speed (ram speed)	mm/s	**1**

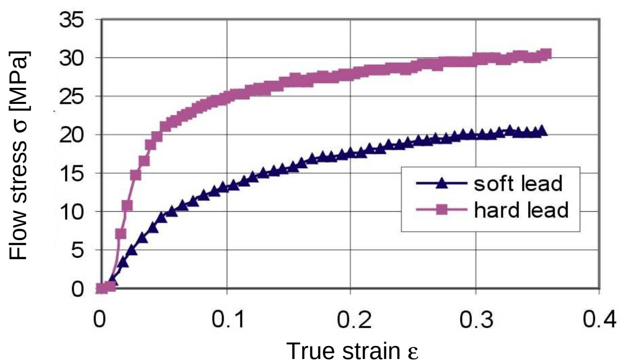


Fig. 3. Stress-strain curves for soft lead and hard lead alloy
Rys. 3. Krzywe naprężenie-odkształcenie dla miękkiego oraz twardego stopu ołowiu

Results and discussion

The analysis of flow of layered metal composite in the extrusion process reflects the change in character of plastic flow of composite material dependently on the kind of used die. Basing on the analysis of grid distortion observed on the longitudinal section of the billet and extrudate (to use the grid distortion method) the identification of plastic and dead zones and distribution of relative velocities of particles have been done (Fig. 4). The improvement of flow characteristics of layered composite in extrusion with use of convex dies has been found. It was found that the radial flow of material of sleeve appears (Fig. 5) – there is no such phenomenon for extrusion using flat dies. Such behavior of composed material can lead to equalization of velocities of particles in the region of the die orifice.

Die geometry has a significant effect on particle velocity distribution in a die opening. In case of extrusion through flat dies, velocity gradient decreases, both for a single layer and the whole composite. It is still significant enough to lead to product defect, resulting in lack of proper layer bonding or cracking of one of the components: core or sleeve. The most favorable type of extrusion considering the most uniform particle flow for each layer is extrusion through convex dies with properly selected angle of the die. Analysis of extrusion effect using all kinds of dies demonstrates that using convex die with die angle of $\alpha = 95 \div 100^{o}$ causes reduction of difference of particle velocity. It suggests that increase of working cone angle over 90^{o} reduces composite layers outflow, especially sleeve material, resulting in better combination of composite components. It is also confirmed by macrostructure tests. Based on images of macrostructures of partly extruded ingot it is possible to observe change of metal flow to the die opening through convex die compared to standard die. In case of extrusion through convex die, shape and volume of dead zone is changed and particles of sleeve material flow to the die opening with significant share of component of radial particle velocity. It has a special significance in case of extrusion of two different materials. For such system, sleeve material may be slowed down and pressed down to core material, and as a result, there may be a better leveling of velocity of outflowing layers, providing durable combination of components. Outflow of metal particles through flat die may force slip effect or lack of combination of composite layers.

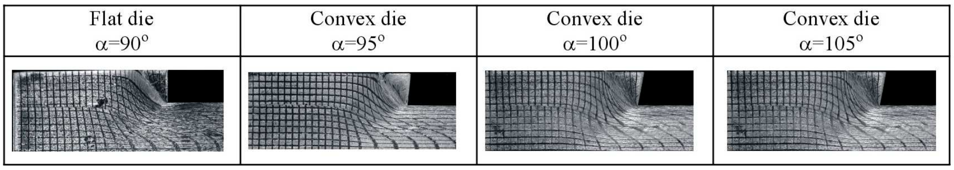


Fig. 4. Grid distortion and configuration of plastic zones in the cross-section of the billet during extrusion of layered composites, extrusion ratio $\lambda = 3$

Rys. 4. Zniekształcenie siatki oraz kształt strefy plastycznej na przekroju wyciskanej próbki kompozytowej, współczynnik odkształcenia $\lambda = 3$

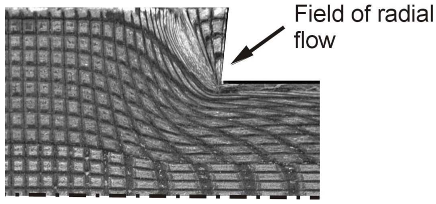


Fig. 5. The field of radial metal flow, which is unique for convex dies
Rys. 5. Obszar promieniowego płynięcia materiału charakterystyczny dla matryc wypukłych

Introduction of two different materials into a single plastic deformation zone causes its shaping dependent on material features and extrusion process parameters. It is especially important to define core and sleeve zone of flow volume. According to calculation results, die geometry has a significant influence on those volumes (Fig. 6). In case of extruding hard core – soft sleeve composite with extrusion ratio of λ = 3, some minimum zone volume for the die with cone angle equal to λ = 95° can be observed. Extruding composite with extrusion ratio of λ = 12 is related to higher diversity in volume, depending on used die.

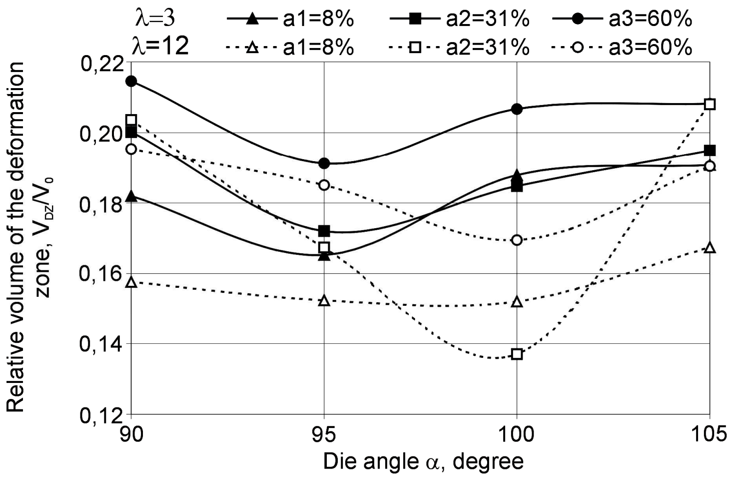


Fig. 6. Effect of die angle on the relative volume of deformation zone for hard core–soft sleeve system
Rys. 6. Wpływ kąta matrycy na objętość względną strefy odkształcenia dla układu twardy rdzeń–miękka powłoka

Increase of die angle over 90° reduces composite layers outflow, especially sleeve material, resulting in better combination of composite components. It is also confirmed by macrostructure tests. Based on images of macrostructures of partly extruded billet it is possible to observe the change of metal flow to the die opening through convex die compared to the standard die. In case of extrusion through convex die, shape and volume of dead zone is changed and particles of sleeve material flow to the die opening with significant share of component of radial particle velocity (Fig. 7). It has a special significance in case of extrusion of two different materials. For such system, sleeve material may be slowed down and pressed down to core material, and as a result, there may be a better leveling of velocity of outflowing layers, providing durable combination of components (Fig. 7b). Outflow of metal particles through flat die may force slip effect or lack of combination of composite layers (Fig. 7a).

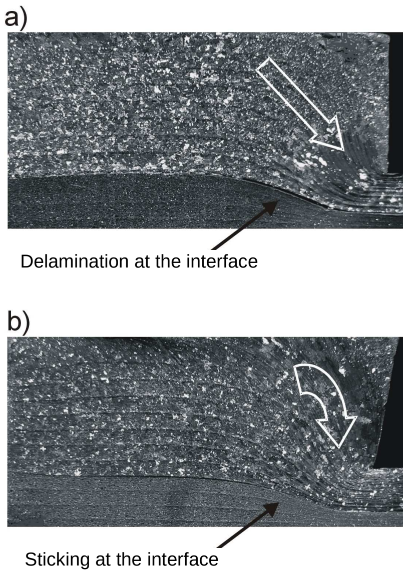


Fig. 7. Metal flow during extrusion of the composite using of flat (a) and (b) convex die

Rys. 7. Płynięcie metalu podczas wyciskania kompozytu przez matryce płaskie (a) oraz wypukłe (b)

The greater volume of deformation zone causes increase of the extrusion load. It depends on the applied die angle. Fig. 10 shows dependence of maximum extrusion force on die angle for tested materials. For hard core – soft sleeve composite with extrusion ratio $\lambda = 3$ there is some minimum value of force in case of extrusion through convex die angle $\alpha = 95^{\circ}$. It concerns all considered volume ratios of core. The largest value of extrusion force for this configuration have been recorded for composite extruded through flat die with volume ratio of core equal to $a_3 = 60\%$ (Vcore/Vcomp. = 0.60). During increase of extrusion ratio from $\lambda = 3$ to $\lambda = 12$, causes observed minimum value to move in the direction of the die with higher die angle, i.e. $\alpha = 100^{\circ}$. The largest extrusion force for extrusion ratio of $\lambda = 3$ is obtained during extrusion of composite with higher considered core volumetric share (through flat die).

Conclusions

Performed experimental tests concerning layer composite extrusion using dies with various geometry allowed the following conclusions:

- Using convex dies with specific geometry selected for specific layer composite causes better leveling of particle velocity in die opening area, justifying their use for extrusion process.
- During extrusion through convex dies there is a change of flow compared to standard dies. Effect of forced partial radial flow (mostly sleeve) favors forcing more favorable flow type and better combination of composite layers, providing better quality of extruded composite.
- Extrusion of layer composites through convex dies leads to decrease of maximum extrusion force for convex die angle from $\alpha = 95 \div 100^{\circ}$ and extrusion load from tested range $\lambda = 3 \div 12$.

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ZASTOSOWANIE MATRYCY WYPUKŁEJ W WYCISKANIU BI-MATERIAŁU

W pracy zaprezentowano wyniki badań eksperymentalnych dotyczących plastycznego płynięcia dwóch różnych materiałów o układzie rdzeń-powłoka w procesie wyciskania. Przeanalizowano wpływ różnych parametrów procesu wyciskania kompozytów warstwowych na plastyczne płynięcie, ze szczególnym uwzględnieniem zastosowania matrycy wypukłej. Badano wpływ konfiguracji wlewka (udział objętościowy i aranżacja składników w materiale wsadowym) na końcowy efekt jednoczesnego odkształcenia materiałów kompozytowych, stosując metaliczne materiały wsadowe: ołów miękki, twardy stop ołowiu z wykorzystaniem kompletu matryc wypukłych. Na podstawie analizy zdeformowanej siatki, zasięgu stref plastycznych, siły wyciskania i rozkładu względnych prędkości cząstek w obszarze otworu matrycy zaproponowano najlepszą geometrię matrycy wypukłej dla danego kompozytu warstwowego, biorąc pod uwagę względnie małą strefę plastyczną, bardziej jednorodne odkształcenie i stosunkowo małą siłę wyciskania. Na podstawie pomiarów siły dokonanych podczas wyciskania przez matryce wypukłe określono zależność maksymalnej siły wyciskania od kąta matrycy.

Słowa kluczowe: wyciskanie, matryca wypukła, materiały kompozytowe

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