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PRELIMINARY INVESTIGATION OF COLD FORWARD, BACKWARD AND RADIAL EXTRUSION OF BI-METALLIC BILLETS

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ABSTRACT

This paper presents several bimetallic operations (forward, backward and radial extrusion). In forward extrusion sleeve aluminium and core copper material were deformed in 90° die. Experimentally obtained results (load-stroke diagram) were compared with analytical calculations. Backward extrusion was performed in a ϕ30mm die with ϕ18.9mm punch. Same material composition as in forward extrusion was used (outer aluminium and inner copper material). Results obtained in experiment (load-stroke diagram) were compared with numerical simulation performed in Simufact Forming 9.0. In the end, numerical simulation and experimental investigation of radial extrusion of gear-like element is presented.
Key words: *Bi-metallic, Al/Cu, Al/Steel, Forward extrusion, Backward extrusion, Radial extrusion*

1. INTRODUCTION

Bi-metallic extrusion is a manufacturing process in which the initial billet is composed of two different materials or two different alloys of the same material. Such a billet is than extruded and final product is obtained, which is consisted of two different materials at different zones of its volume, depending on the initial billet composition and extrusion process development.
Manufacturing of bi-metallic products by extrusion enables beneficial utilisation of favourable properties of both materials. So, for instance, bi-metallic extruded component can consist of inner stronger material (e.g. steel) which is surrounded by outer sleeve which is softer and has anti-corrosion characteristics. Another typical application is fabrication of plain bearings, where only the inner layer is made of anti-frictional metal and outer carrier is produced by stronger steel.
There are a number of different properties of the materials which can be exploited and combined in the bi-metallic extrusion such as thermal expansion, electric conduction, anti-corrosion, mechanical strength etc.
Main problem which occurs in the fabrication of bi-metallic products are different properties of employed materials which cause different velocity fields during deformation, i.e. different material

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flows. To some extend this problem can be overcome by optimal billet design and proper choice of influential process parameters.
A number of theoretical and experimental investigations have been conducted in the field of bi-metallic extrusion.
Bi-metallic rod extrusion has been elaborated in [1]. Authors made experimental analysis of the forward extrusion using model materials (hard and soft plasticine). Velocity and stress field for chosen billet geometries were predicted by numerical analysis. Influence of core and sleeve component on final product shape was determined.
In [2] main factors which have impact at forward bi/metallic extrusion are summarized:
1. Percentage reduction in area r (%) of extrusion ratio R
2. Semi-cone die angle α
3. Length of the land of the die L
4. Friction factor between the billet and the container wall m
5. Ratio of the core and sleeve radius R_C/R_0
6. Ratio of the core and sleeve flow stress Y_{0C}/Y_{0S}
7. The presence of front tension
8. The interfacial bond strength between the sleeve and core

Production of bi/metallic coins has been studied in [3]. Finite element analysis as well as experimental investigation have been performed in order to obtain optimal shape of both coin materials. Load to split the central part from the outer ring of the coin has been determined experimentally.
Influence of die geometry on plastic flow during forward extrusion is described in [4]. Experimental test, using hard and soft lead, showed that convex dies enable better equalization of particle velocity in a die outlet. Wohletz et al. in [5] investigated combined forward-backward bimetallic extrusion of aluminum and steel. Surface enlargement and bonding strength were analyzed in detail. Different surface qualities (polished and brushed) of both materials were varied. Results show that better surface bonding occurs for brushed samples. Authors in [6] conducted bimetallic radial extrusion of gear element. Thin outer steel ring and inner aluminum cylinder were used as a billet material. The experiment was performed at elevated temperature (steel to 1150°C and aluminum to 550°C). Thickness of outer sleeve at various positions was measured.
The purpose of current work is to present some preliminary experimental, numerical and analytical investigations of forward, backward and radial bi-metallic extrusion.

2. FORWARD BI-METALLIC EXTRUSION

2.1 Experimental investigation

Experiment of forward bi-metallic extrusion was performed at Laboratory for Metal Forming at Faculty of Technical Science, Novi Sad, Serbia. Schematic of bi-metallic forward extrusion is presented in **Fig.1**. Pure aluminum was used as softer sleeve material while copper was used as harder core. Stress – strain curves for both materials ware determined by Rastegaiev test:

$$\sigma_{Cu} = 315 \cdot \varphi^{0.54} \text{ [MPa]} \quad (1)$$

$$\sigma_{Al} = 127.5 \cdot \varphi^{0.2} \text{ [MPa]} \quad (2)$$

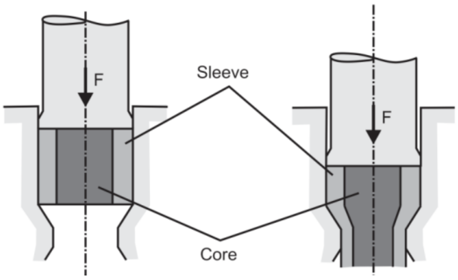

Fig.1*– Forward bi-metallic extrusion at the beginning (left) and during process (right)*

Photograph of aluminum sleeve and copper core and billet initial dimensions are shown in **Fig.2**. Experiments were performed on Sack &Kiesselbach hydraulic press with nominal force of 6300kN.

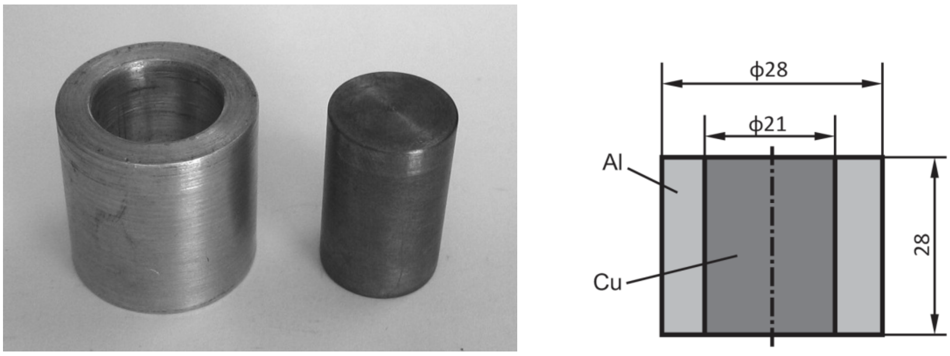

Fig.2 *– Photograph of aluminium sleeve and copper core and dimensions of composed billet*

Prior to deformation, billet was lubricated with oil.**Fig.3** shows billet composition after extrusion. During the experimentforce – stroke diagram was recorded.

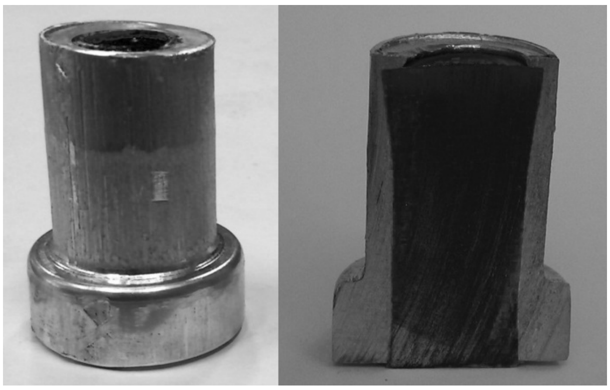

Fig.3 *– Billet composition after extrusion. Left: full billet, right: cross-section*

2.2Analytical calculation

Analytical approach was employed in order to make a comparison with experimental results. Force during extrusion process was calculated by using common expression for forward extrusion [7]:

$$F = A_0 \cdot K_{\mathrm{sr}} \cdot \varphi \cdot \left(1 + \frac{\mu}{\alpha} + \frac{2}{3}\frac{\alpha}{\varphi}\right) + 4 \cdot \mu \cdot K_0 \cdot \frac{h_1}{D_0} A_0 \qquad (3)$$

where:

A_0 – punch area
$Ksr=(K_0+K_1)/2$, K_0 – effective stress at beginning of the process, K_1 – effective stress after material deformation
φ – logarithmic deformation, $\varphi=2\cdot\ln(D_0/d_1)$
μ – friction coefficient
α – die angle
h_1 – billet's current height in the die (where D_0 = 28 mm)
D_0 – billet's initial diameter
d_1 – billet's extruded diameter

This expression is valid for single material billet. For bi-metallic cases, effective stress was calculated as an average value for both materials:

$$K = \%V_{\mathrm{Al}} \cdot K_{\mathrm{Al}} + \%V_{\mathrm{Cu}} \cdot K_{\mathrm{Cu}} \qquad (4)$$

where:

K – effective stress of bi-metallic composition,
K_{Al}, K_{Cu} – effective stress of aluminium and copper
$\%V_{Al}$, $\%V_{Cu}$ – volume fraction of each segment in bi-metallic billet.

Fig. 4 shows comparison of force – stroke curve obtained analytically and experimentally. Initially, force increases very rapidly, which is latter followed by steady decreasing phase. As it is evident from the Fig.4. the experimental and analytical curves show very good agreement.

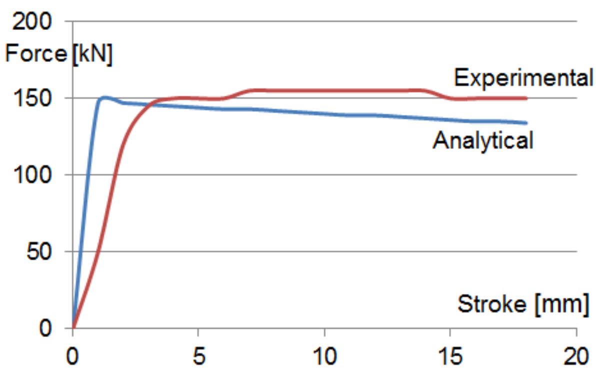

Fig. 4 – Force – stroke diagram obtained by experiment and analytical calculation

3. BACKWARD BI-METALLIC EXTRUSION

3.1 Experimental investigation

Principle of this experimental investigation is shown in **Fig.5**. Copper was used for inner material, while aluminum was used for outer (sleeve) material. Dimensions of the billet are presented in ***Fig.6***. Extrusion punch was slightly smaller in diameter (ϕ18.9mm) then Cu-segment. Stress – strain curve for both materials ware determined by Rastegaiev test.

$$\sigma_{cu} = 362.67 \cdot \varphi^{0.1828} \quad (5)$$

$$\sigma_{al} = 191 \cdot \varphi^{0.}165 \quad (6)$$

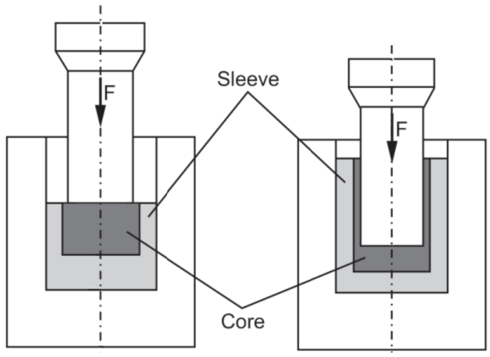

Fig.5 *- Backward bi-metallic extrusion at the beginning (left) and during process (right)*

Fig.6 *- Photograph of aluminum sleeve and copper core and dimensions of composed billet*

3.2Numerical analysis

Numerical simulation was carried out by Simufact Forming 10.0 software. Due to axial-symmetry of the process, a 2D simulation was performed. Advanced Front Quad mesher with 0.25mm and 0.65mm elements size were used for Cu and Al material, retrospectively. Punch and die were set as rigid non-deformable bodies. Friction coefficient was μ=0.12. More about friction evaluation can be found in [8].

3.3 Results comparison

Fig.7shows comparison between experimental and numerical simulation at the end of the process as well as relevant geometrical dimensions. It can be observed that experiment and simulation are in very good agreement as far as material flow is considered. At first, copper billet flows in sideway direction, pushes the aluminum and creates a thin layer in middle segment. In upper segment a certain amount of separation between Al and Cu takes place.

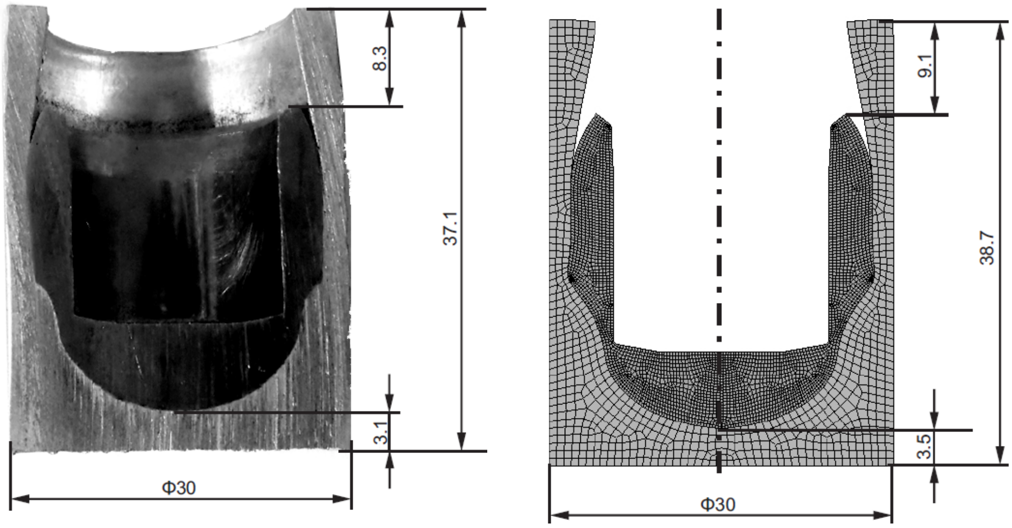

Fig.7 – *Comparison between experiment and numerical simulation at the end of the process*

Figure 8 provides force – stroke curve comparison between experiment and numerical simulation. Both curves show very good correlation.

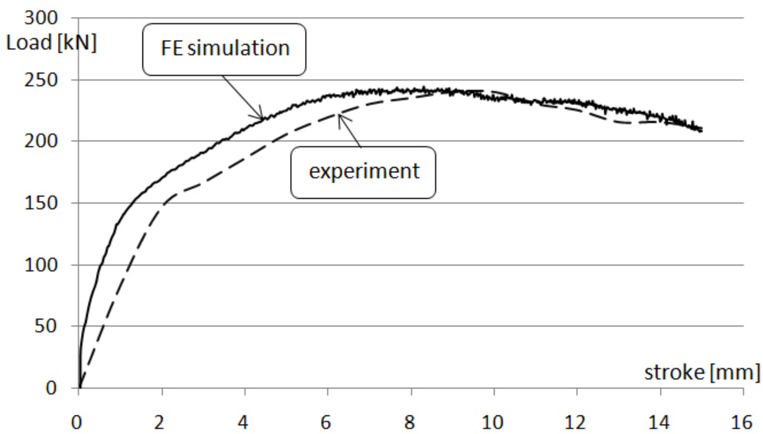

Fig.8 – *Force-stroke diagrams obtained by experimental investigation and FE simulation*

4. RADIAL BI-METALLIC EXTRUSION

Preliminary research of radial extrusion of gear-like elements was also performed. Simulation was carried out in Simufact Forming 11.0 software with billet and die geometry shown in **Fig.9**.

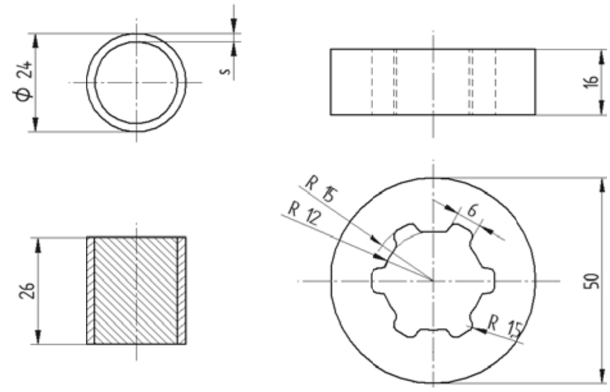

Fig.9 *– Initial billet and die insert for gear-like element radial extrusion simulation*

Fig.10 shows shape of the billet during different extrusion stages. During this simulation process, several different outer sleeve thicknesses were varied and corresponding force – load curves were obtained.

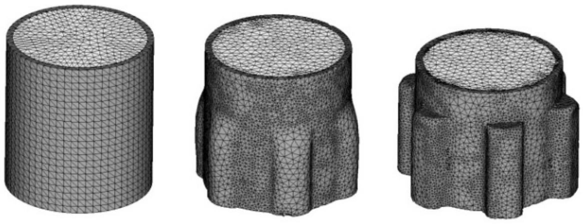

Fig.10 *– Workpiece at the beginning, during and at the end of simulation [9]*

An experimental investigation of similar shaped part as in simulation was performed as well. Initial billet and final shape of the workpiece are presented in ***Fig.11***.

Fig.11 *– Disassembled Al/Steel billet (left) and workpiece after radial extrusion (right)*

5. CONCLUSIONS

In bi-metallic extrusion two different metal materials are deformed simultaneously into a desired shape. The most common material combinations that can be deformed together are Cu/Steel, Cu/Al, Al/Steel. Even the same material types but different alloy composition can be deformed (i.e. softer and harder steel). Usually, materials are composed in such a manner that one material is at the outer surface of the part (sleeve) and other material is inside (core). This kind of metal forming enables production of parts that have different specific characteristics on different sections. For example, outer steel material of a rod ensures high strength and inner core aluminum enables low weight. Other combination examples are: stronger (expensive) and softer (cheaper) steel, conductible copper and strong steel, etc.

In this paper preliminary investigation of various bi-metallic extrusion processes have been elaborated. In forward extrusion, a copper core and aluminum sleeve material have been experimentally deformed and results were compared to analytical calculations. Backward extrusion of Al/Cu billet combination was performed both experimentally and numerically. Results obtained by experiment and FE simulations exhibit very good agreement. Finally numerical simulation and experiment of radial gear-like elements are shown.

In future work on this subject more intensive and detailed investigations of presented processes are planned in the laboratory for Metal Forming. Obtained results will be presented in the relevant literature.

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PRELIMINARNA ISTRAŽIVANJA HLADNOG ISTOSMERNOG, SUPROTNOSMERNOG I RADIJALNOG ISTISKIVANJA BIMETALNIH PRIPREMAKA

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REZIME

U ovom radu istraživane su tri operacije istiskivanja bimetalnih pripremaka (istosmerno, suprotnosmerno i radijalno). Istiskivanje bimetalnih pripremaka je proizvodni proces u kome se inicijalni pripremak sastoji od dve ili više različitih legura. Takav pripremak se zatim istiskuje i na kraju se dobija finalni deo koji se sastoji od dva ili više različita materijala na različitim zonama u zapremini. Na taj način se mogu iskoristiti najpogodnije karakteristike svakog materijala na željenim zonama.

Prilikom istraživanja istosmernog bimetalnog istiskivanja, za pripremke su uzeti delovi od aluminijuma i bakra (bakar kao cilindar unutra, a aluminijum kao prsten spolja). Dobijeni rezultati u vidu dijagrama sila-hod su upoređeni sa rezultatima dobijenim analitičkim putem. Suprotnosmerno istiskivanje je takođe vršeno sa kombinacijom materijala bakar/aluminijum. Rezultati su poređeni sa numeričkom simulacijom procesa vršenom u programskom paketu SimufactForming 9.0. Proces radijalnog istiskivanja delova nalik zupčanicima je takođe numerički simulirano, a zatim i eksperimentalno. Kao unutrašnji materijal uzet je aluminijum, a kao spoljašnji čelik. Prednost ovakvog vida bimetalnog deformisanja je dobijanje lakih zupčanika sa ojačanim spoljašnjim slojem čelika.

Ključne reči: *Bimetal, Al/Cu, Al/čelik, Istosmerno istiskivanje, Suprotnosmerno istiskivanje, Radijalno istiskivanje*