BI-METALLIC COLD BACKWARD EXTRUSION – NUMERICAL SIMULATION WITH EXPERIMENTAL VERIFICATION

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Abstract. Bi-metallic extrusion is a metal forming operation where billet is composed of two different metallic materials which are then concurrently extruded into a final workpiece. In this way final component, consisting of two different materials which are metallurgically bonded, is created. Extrusion of bi-metallic workpieces differs in many aspects from the classical single-metal extrusion. Although bi-metallic extrusion enables beneficial utilization of favourable characteristics of both paired materials, this process has not been often applied in the industrial practice so far. This is mainly due to the certain dearth of knowledge and experience in this field.
The present study is bound to the backward extrusion of bi-metallic materials. Combination of Al-Cu as a billet composition is explored numerically and experimentally. Material flow as well as mechanical properties of the obtained bi-metallic component have been determined and analysed.

Introduction

Cold extrusion of mono-metal billets is well established technology which makes it possible to manufacture small and middle size components in very efficient way. There are numerous advantages of this technology when compared to other manufacturing methods such as better material utilization, short production time, excellent mechanical properties and surface quality of extruded workpieces.

Further investigation of cold extrusion goes in various directions. One of the significant research fields in this context is development of a new extrusion processes which would enable even wider industrial application of this technology.

Bi-metallic cold extrusion is a modern metal forming operation where an initial billet, consisting of two or more different materials, is extruded and, as a result, multiple material component is produced. In most cases billet consists of two different materials, although combination of two different alloys of the same material is also applicable. Application of bi-metallic extrusion enables beneficial utilization of favourable characteristics of both extruded materials.

During concurrent extrusion of composite billet metallurgical bound between different billets components is created, which omits the need for additional subsequent joining of two materials.

Different geometrical shapes of the bi-metallic workpiece can be produced, but in most cases bi-metallic components are in the form of core-sleeve configuration. So, for instance, sleeve material can be used as a layer because of a favourable anti-corrosions properties and core material can be chosen as a carrier due to lower weight and price. Many other requirements of the product can be fulfilled by proper choice of both materials in bi-metallic extrusion (e.g. thermal expansion, mechanical strength, electric conduction). As one example in [] has been reported that bimetallic copper/aluminium road is 40-60% lighter and 30-40% cheaper in comparison with Cu road.

One of the main challenge which has to be solved in bi-metallic extrusion is occurrence of different flow patterns of both applied materials. Softer material flows easier and its velocity field differs from other paired material. This leads to non-homogenous thickness of metal layer or – in extreme case – to the cracks in softer or harder material. In order to produce sound bi-metallic component all significant influential parameters should be chosen in proper way.

Bi-metallic extrusion

Bi-metallic extrusion is applied in most cases in three different geometrical forms: forward extrusion, backward extrusion and tube extrusion. In forward extrusion bi-metallic billet, composed of outer sleeve and inner core, is extruded by the punch through the die-opening and, as a result, bi-metallic rod is produced, figure 1a.

Bi-metallic tubes and tube-like hollow components can be produced by two different extrusion methods: forward tube extrusion by the punch provided with the mandrel (Fig. 1b) [1] and extrusion-piercing in a profiled die using the punch and separate mandrel (Fig. 1c) [2].

In all cases material combination can be twofold, depending on the requirements of the final workpiece: a) hard sleeve material and soft core material, b) soft sleeve material and hard core material.

Process of bi-matallic extrusion has been investigated by a number of authors. In [3] bi-metallic extrusion of tubes by using profile dies and mandrels is elaborated. Theoretical results obtained by slab method are compared with experiment and fair agreement was found. Geometrical configuration of billet and die and its impact on the workpiece tolerance in bi-metallic tube extrusion is studied in [4]. Novel billet design has been proposed which decreases the “out of tolerance” geometry.

Research on backward bi-metallic extrusion has been reported in [4] [5]. Experimental part of the investigation was performed by using hard plastiline / soft plastiline combination. Focus has been placed on the layer thickness homogeneity. Velocity field and theoretical analysis was carried out by Upper Bound method.

Among diverse process parameters which affect the quality of final product, initial billet geometry is one of the most significant. In [6] authors investigated forward extrusion and concluded that not only ratio of core /sleeve radius, but also ratio of the core / sleeve length influences the dimensional stability of the rod longitudinal cross section. They proposed one optimal initial core material length for every concrete extrusion case (reduction in area, die angle, die land, flow stress of sleeve and core materials) which, as a result, gives a correct product. Impact of die geometry in the strength of the bond between two materials in forward extrusion was investigated in [7]. It was concluded by FE analysis and by experimental research that die angle of 25% results in optimum velocity field and, consequently, highest shear strength of the bond.

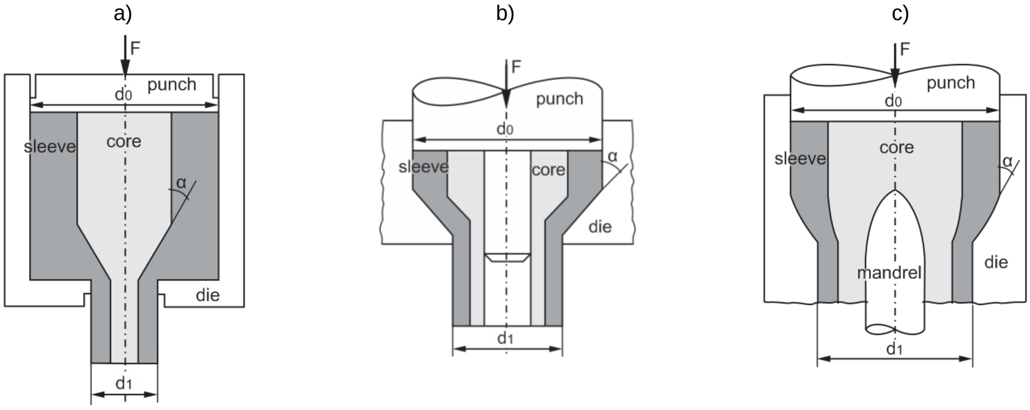

Fig. 1 Different variants of bi-metallic extrusion a.) forward extrusion b. and c.) tube extrusion

In the current paper investigation of bi-metallic backward extrusion process is presented. Billet with the Al/Cu combination has been used. Numerical analysis (FE) and experimental work were performed in order to explore material flow, geometry of the extruded product as well as the required extrusion force.

Experimental investigation

Bi-metallic billets were composed of Al outer sleeve and Cu inner core (Figures 2 and 3.). Dimensions of the composite billet placed in the die are also shown in Fig. 2 Punch (1) has a slightly smaller diameter than Cu-core (18.9 mm compared to 22 mm). Flow curves for both billet materials are obtained in Rastegaev test:

$\sigma_{cu} = 362.67 \cdot \varphi^{0.1828}$ (Cu) (1)

$\sigma_{al} = 191 \cdot \varphi^{0.165}$ (Al) (2)

Before extrusion billet was lubricated by mineral oil.

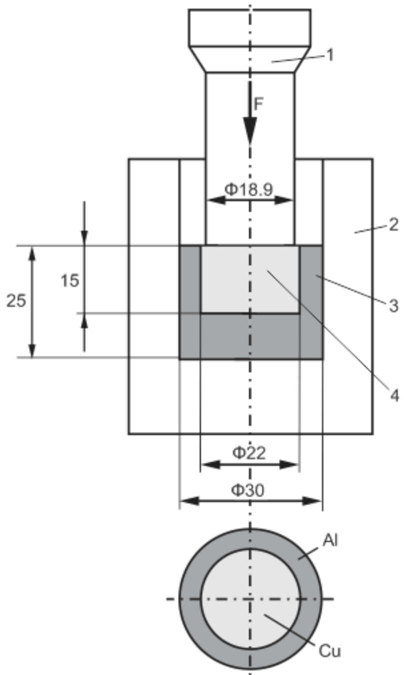

Fig. 2. Configuration of billet and die
(1 – punch, 2 – die, 3 – Al, 4 – Cu)

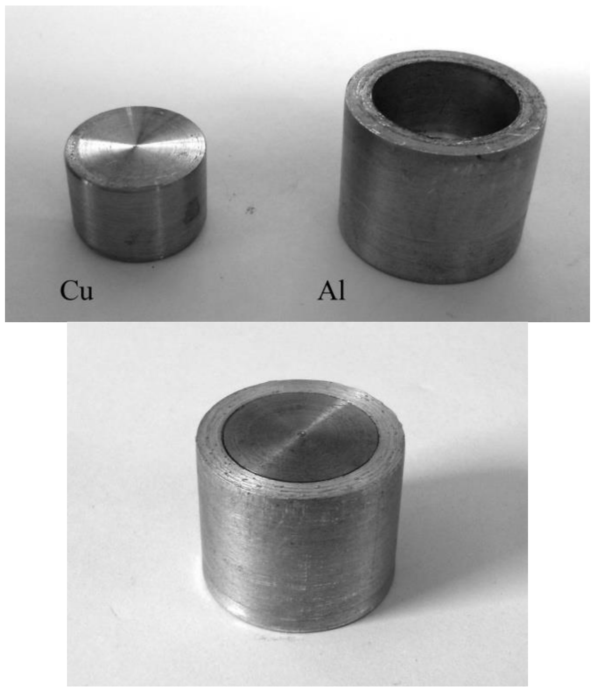

Fig 3. Photograph of separated copper and aluminium parts (above) and composed billet (below)

In order to assemble Cu-core into Al-sleeve in proper way, geometrical overlapping between both parts was made and aluminium was preheated and copper was cooled so that an adequate fit could be achieved. During extrusion force – stroke diagram was recorded. At the end of the operation bi-metallic workpiece was ejected from the die by ejector which is integral part of the press at which extrusion was performed (Sack & Kiesselbach Hydraulic 6.3 MN press).

Photographs of the backward extrusion tooling and extruded workpiece cut through the meridian plane are given in Fig. 4 and 5.

Numerical simulation

Numerical simulations by Finite Elements method was carried out in Simufact Forming 10.0. Due to symmetrical nature of the process axisymmetric 2D simulation was performed. In simulation, identical geometrical data (tool, die and billets dimensions), tool stroke, tool velocity and materials were employed as in the experiment. Hydraulic press with 0.1 tool velocity was used. Material was modelled as an isotropic elasto-plastic body and punch and die were set as rigid bodies without heat conduction. Both Cu and Al parts were divided by 0.25 mm and 0.65 mm element sized mesh retrospectively, with Advanced Front Quad mesher and *quads (10)* element type. Friction factor in all three different interfaces (Cu/Al, Cu/Tool and Al/die) was set to be m = 0.12, which corresponds to the friction magnitude when lubrication with mineral oil is applied [8].

Fig. 4. Tooling for bi-metallic backward extrusion

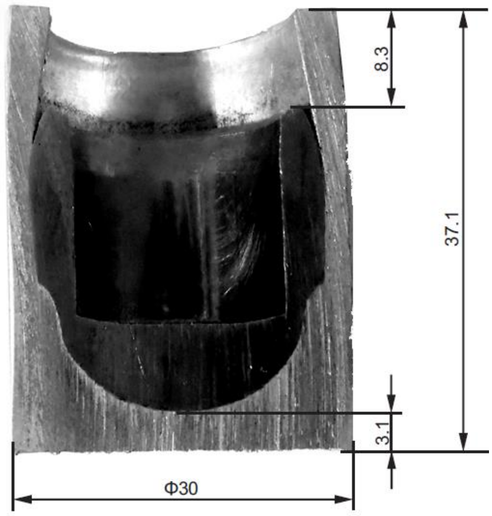

Fig. 5. Meridian cross section of the final experimental workpiece (stroke s = 15 mm)

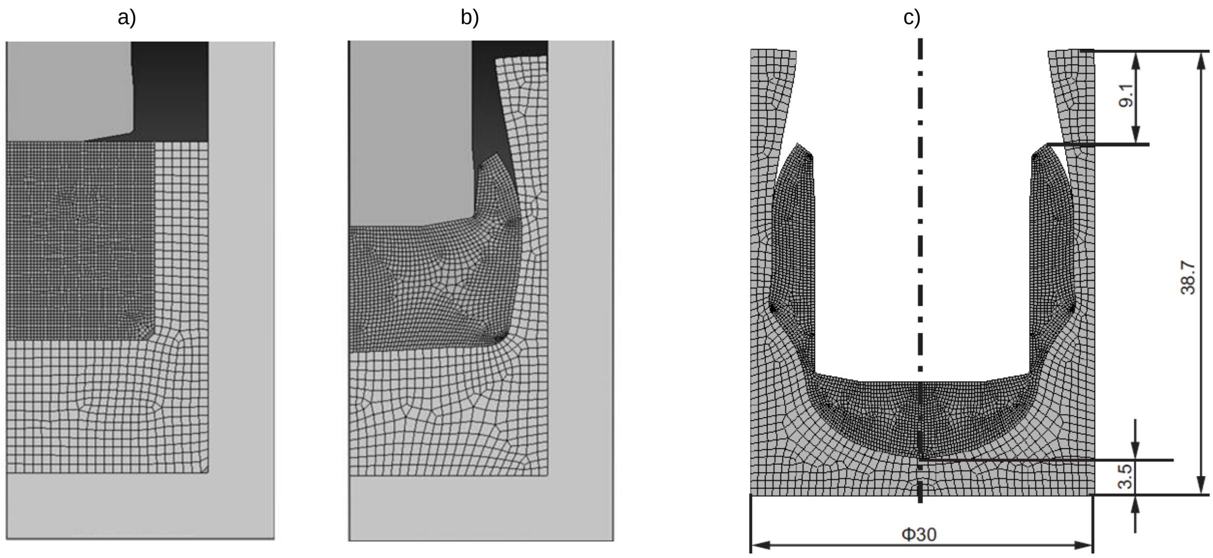

Fig. 6. Numerical simulation: a) start, b) intermediate phase after 6 mm punch stroke and c) end of the process (full cross-section)

Results and concluding remarks

Figure 6a shows initial position in the numerical analysis and division of both billet components into finite elements. Intermediate constellation after 6 mm punch stroke is given in Fig. 6b. As it can be seen copper billet flows sideways and creates a slightly barrel shape. This occurs due to the fact that copper material is significantly stronger than aluminium. In latter phase, this barrelled shape moves upwards and a thin layer is formed on the lower part of the workpiece – Fig 6c. With the progressing punch travel, certain amount of separation between Al and Cu segments takes place in the upper part of the workpiece assembly. Process was terminated after 15 mm punch stroke (Fig. 6c).

By comparing figures 5 and 6c (meridian plane of the workpiece at the end of the process – experiment and numerical simulation), close agreement in the geometrical form of obtained workpiece can be observed. Also, load – stroke diagrams obtained numerically and by experiment show favourable coincidence (Fig. 7). Certain load decline after the punch stroke of ≈8 mm can be attributed to the separation between Al and Cu component. This separation causes decrease of friction amount between Al and Cu materials, which results in load decline.

Future work on current issue will include further optimization of the process in order to obtain sound workpieces, i.e. workpieces with constant layer thickness and with constant bound between two components of the workpiece. In this regard planned investigation would consider different material combinations as well as various geometrical constellations of the bi-metallic assembly.

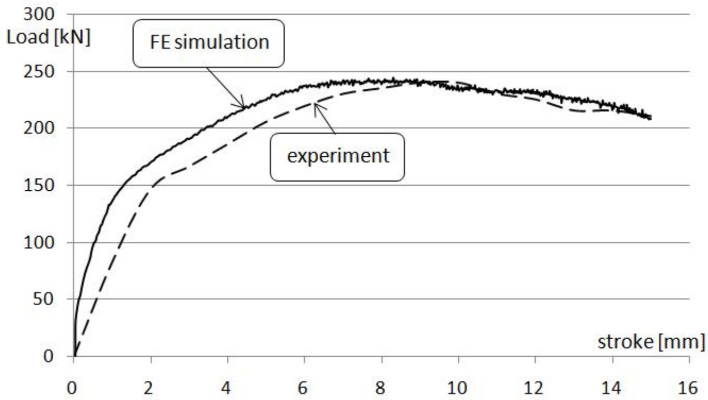

Fig. 7. Load stroke diagrams obtained by experimental investigation and FE simulation

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