MATERIAL FLOW ANALYSIS OF BIMETALLIC HOLLOW DISC UPSETTING

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Abstract
Bimetallic materials have a growing area of usage and named a type of composite materials with combining advantageous features of two different materials. Upsetting of discs obtained by aluminum and copper was studied. The FEM method was used to simulate the process and results were compared with experiments by taking material flow into account. It was determined that material flow increased with height and reduction rates and on the middle axis the material flow was highest. On the interfaces of sleeve and core materials separation after forming was not observed. Also, it was understood that simulation results of bimetallic disc sample obtained with FEM based DEFORM-3D software in upsetting procedure were in concordance with experimental results and FEM model can be useful for future studies.

Key words: bimetallic materials, upsetting, DEFORM-3D, material flow, load analysis, finite element method.

INTRODUCTION

As the time goes on and different needs emerge composite materials' areas of usage are steadily increasing. Bimetallic materials are named as composite materials because of acting like a single material with combining different alloys of the same material or a new material by bringing two types of different materials together physically. Bimetallic materials can have superior properties by composing of two different materials. Bimetallic materials are commonly selected for their corrosion resistance, low costs, weight disposition and fatigue strength. For example a bimetallic material which was obtained by using aluminum in inner part and steel in outer part shall be lighter than whole steel material and more durable than whole aluminum material. Manufacturing methods of bimetallic materials are mostly limited with coating, close fitting and casting, even though, the first examples of bimetallic materials produced by upsetting method were dating back to old times. Nowadays, application area of bimetallic materials is getting bigger and bigger. Nevertheless there are not too many studies regarding forming bimetallic materials.

CHITKARA AND ALEEM (2001) compared the obtained experimental results with analyses for axisymmetric extrusion of bimetallic tubes**.** HAGHIGHAT AND ASGARI (2011) proposed a new spherical velocity field for extrusion of bi-metallic materials and obtained numerical results. KAZANOWSKI, EPLER, AND MISIOLEK (2004) investigated the relation between initial geometries and the quality of the product with the influence of the initial billet geometry on the product geometry during bi-material rod extrusion. HAGHIGHAT AND MAHDAVI (2013) offered a kinematically admissible velocity field for bimetal tube extrusion process through rotating conical dies. YEH AND WU (2005) investigated the upsetting rings. They used variational upper bound method to evaluate the bulge profile of the upset ring and compared the results with upper bound and FEM results. WIFI ET AL. (1996) selected an updated Lagrangian, elasto-plastic large strain finite element code for mathematical approach to the upsetting disc problem. PLANCAK ET.AL.(2011) investigated the forming of two different geometries in closed die by using two different materials as a bimetallic material and also obtained the forming load, material flow. KACMARCIK ET AL. (2013) obtained experimental and numerical results from backward extrusion of bimetallic materials for gear like profiles. EIVANI AND TAHERI (2007) studied ECAE process for a new method for producing bimetallic. BARATA MARQUES AND MARTINS (1991) made simulations for the joint of a bi-metal coin to obtain forming load and strain field. ESSA ET AL. (2012) investigated interface of these two components using cylindrical samples with different H/D ratios by using C15E as softer material for core and stronger material C45E as sleeve for upsetting experiments.

In the presented study; upsetting of bimetallic hollow discs was investigated by using commercially pure aluminum as sleeve material and electrolytic copper as core material. Material flow was selected as main parameters for the analyses. The FEM model was built for disc upsetting process and results were compared with experimental results. Material flow was investigated by comparing cross sectional views of simulations and upsetting products of the experiments. Both experimental and FEM results agree well each other and the obtained model can be expand to further studies for the different process parameters.

MATERIALS AND METHODS

Commercially pure aluminum (Al 1070) and electrolytic copper was selected as bimetallic material. Al 1070 aluminum was sleeve material in view of its higher mechanical properties comparing to core material which was electrolytic copper. Stress-strain curves of the materials were given in Eq. 1 and Eq. 2.

$$\sigma_{al} = 144\varepsilon^{0.162} \quad (1)$$

$$\sigma_{cu} = 319\varepsilon^{0.583} \quad (2)$$

The dimensions of the bimetallic samples can be seen in the Fig. 1.

Experiments were carried out by Universal test machine which has 600 kN capacity. The press was controlled by software to obtain the load-displacement curves. Experimental setup was given in Fig. 2. Billets were compressed using flat faced platens. The surfaces of the platens were cleaned with acetone to ensure the same friction conditions for all specimens for each test. The cylindrical specimens were centered on the lower die and were upset at different deformation ratios. Height in reductions for 10%, 20%, 30% ratios were calculated and selected for the experimental study.

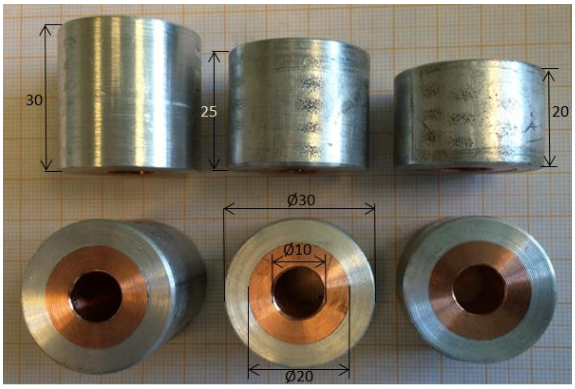

Fig. 1. – Photographical views of workpieces and dimensions

The load-displacement diagram was obtained by data taken from the software. After upsetting, the specimens were cut into two parts from the midsection with MICROCUT 1050 machine to observe material flow of the samples.

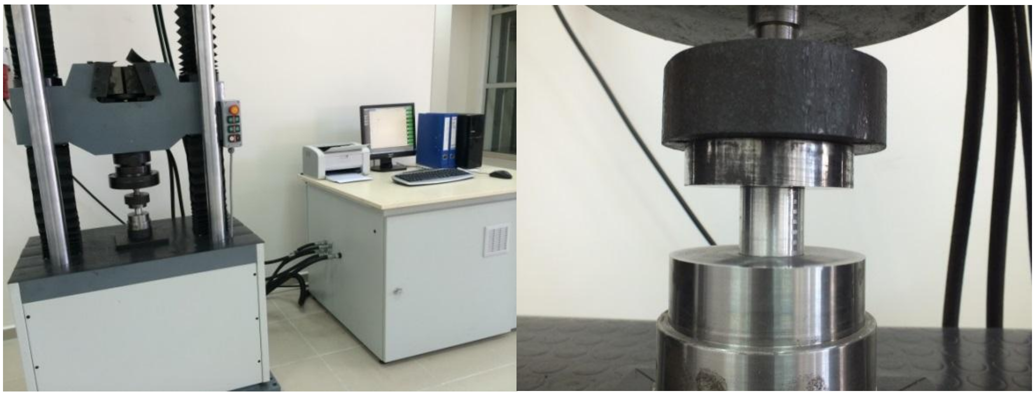

Fig. 2. – Experimental setup

Finite element method was commonly preferred for complex engineering problems. DEFORM is a FEM based software which was specialized for metal forming processes. DEFORM-3D v10.2 was used for simulations. Geometries were modeled in a CAD system, and exported to DEFORM-3D software. The model can be seen in Fig. 3. Mesh distribution in the FEM method is very important to obtain accurate results from the simulations. Environment temperature is defined as room temperature same as experiments. Press velocity was selected as 0.1 mm/sec to correspond with experiments. The friction type considered as shear and the friction factors (m) between workpiece and the dies are assumed as constant and it was selected as m=0.4 for Aluminum/Die contact surfaces and m=0.4 was selected for Copper/Die contact surfaces obtained from the ring compression test. Friction was assumed as zero at the aluminum and copper interface. The iteration method selected as direct and the type of the simulation was Lagrangian Incremental. The dies are selected as rigid bodies and all elastic and plastic deformations of the dies are neglected. H13 steel was selected as a die material from the software library.

CDA 110 was selected for core material and ALUMINIUM 1070A was for sleeve material in the FEM simulations. 35.000 elements was used for both workpiece materials' were models for accurate FEM results. The convergence error limit for velocity and force were 0.005 and 0.05 respectively. The global remeshing was chosen and the type of interference depth selected as relative and its value considered as 0.7. The Conjugate-Gradient solver has been used to solve the problem.

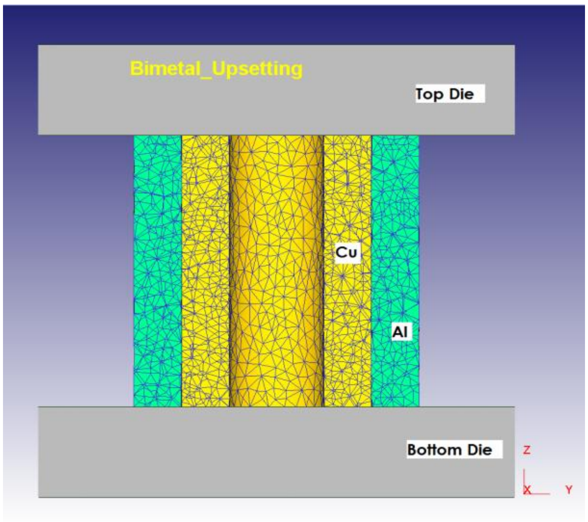

Fig. 3. – View of the FEM model of the die assembly and the bimetallic material

RESULTS AND DISCUSSION

In this study, effective parameter for upsetting of bimetallic disc was firstly investigated and analysis parameters were decided as upsetting load and material flow. FEM model was constructed by DEFORM-3D software and the simulation results were compared with experimental ones.

Material Flow Analysis

After the forming bimetal samples processed with upsetting procedure were cut through axis of symmetry by using MICROCUT 1050 sensitive cutting machine. Flow of materials composing sleeve and core parts are examined. Behavior of material flow is related with height and friction. Since friction factor is the same for the study, reduction in height is investigated for the study and for this purpose; real samples were compared with material flow profiles in the simulations. Samples are processed such in a manner that their lengths are 30 mm, 25 mm. and 20 mm. in the experiments. They are formed in the rates of 10 %, 20 % and 30 % reduction. In order to examine product material's flow middle axis is used as base, inner diameter and outer diameter values of the disc from middle axis are measured on products and simulations as it is given in Fig. 4.

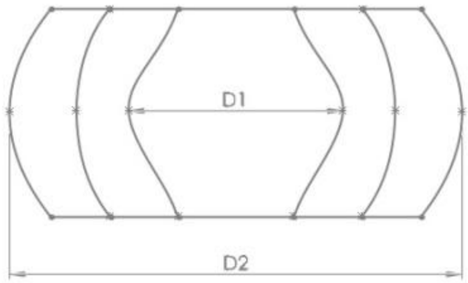

Fig. 4. - Measurement points of the samples

The workpieces was measured from the middle axis of the samples after upsetting according to Fig. 4 and the material flow of the samples was analyzed with reference to the Tab. 1 results.

For 10% reduction; the differences between the measured values of the simulations and products for the outer diameter are getting higher when the initial height increases.

Tab. 1. – Measurement values of simulation and experimental results

Product	**D1 (mm)**	**D2 (mm)**	
H30%10	*10.44*	*31.79*	**Exp.**
	10.53	*31.65*	**FEM**
H30%20	*11.26*	*33.56*	**Exp.**
	11.31	*33.78*	**FEM**
H30%30	*12.24*	*36.07*	**Exp.**
	12.33	*36.23*	**FEM**
H25%10	*10.41*	*31.68*	**Exp.**
	10.50	*31.60*	**FEM**
H25%20	*11.17*	*33.24*	**Exp.**
	11.26	*33.49*	**FEM**
H25%30	*12.16*	*36.08*	**Exp.**
	12.28	*35.83*	**FEM**
H20%10	*10.36*	*31.44*	**Exp.**
	10.48	*31.51*	**FEM**
H20%20	*11.08*	*32.52*	**Exp.**
	11.21	*32.86*	**FEM**
H20%30	*11.82*	*35.68*	**Exp.**
	11.89	*35.39*	**FEM**

When the reduction in height increases for the outer profiles, the simulation and experimental measured values converge. The difference for the inner profile does not change entirely for all reduction rates. Visual comparisons regarding to material flow after upsetting are given in Fig. 5, Fig. 6 and Fig. 7.

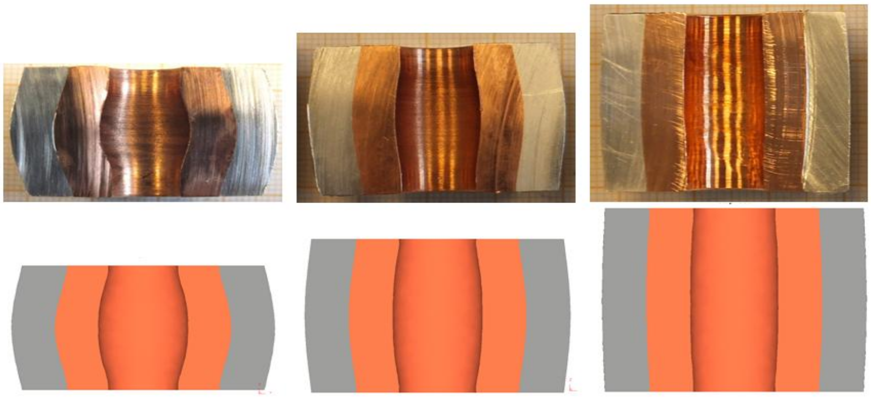

Fig. 5. – Cross section views of the midplane of experimental products and FEM models for the 30 mm. initial height. (A= 30% red., B= 20% red., C= 10% red.)

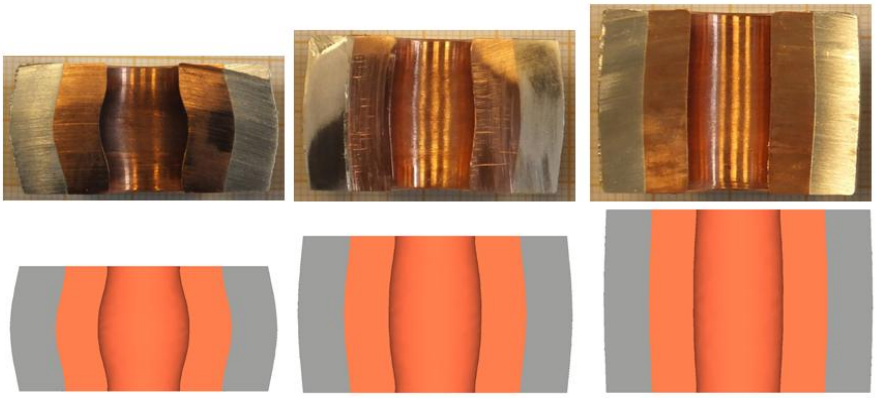

Fig. 6. – Cross section views of the midplane of experimental products and FEM models for the 25 mm. initial height. (A= 30% red., B= 20% red., C= 10% red.)

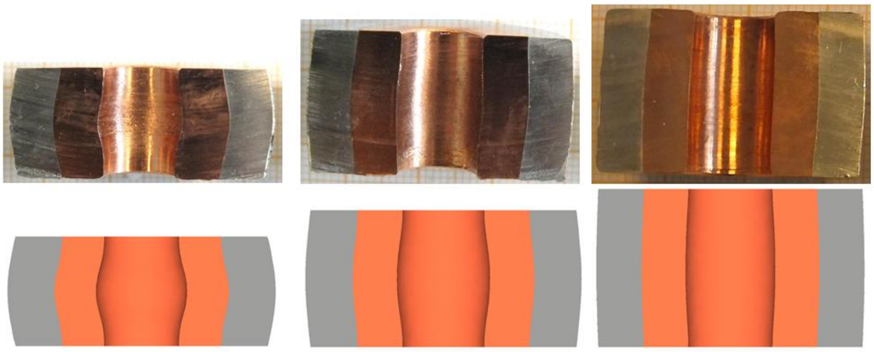

Fig. 7. – Cross section views of the midplane of experimental products and FEM models for the 20 mm. initial height. (A= 30% red., B= 20% red., C= 10% red.)

When 30 mm. height samples are examined after forming, it was observed that for 10% reduction the highest similarity is obtained in the comparison of product and simulation profiles. It was observed that material flows on the core/sleeve material interfaces are rather similar. And for 20% and 30% reduction, it was also observed outer profiles of the products are quite familiar but in the inner side, similarity is not fit with simulations.

For 25 mm. initial height, it is clear that sleeve material's outer diameter flow profile is similar to the product. In addition to that it was determined that at each % reduction rate increase material flow on core/sleeve material interfaces is in concordance with simulation. Similarly, it was observed that profile on the inner surface of the core material on the disc where there is hole was in concordance with simulations.

Like after forming samples with 20 mm. initial length for 30% reduction; it was observed that material flow is match with real product profiles on both on core material inner diameter middle axis and on the sleeve material outer diameter profile and it can be seen that material flow modeling was in concordance with actual experiments.

After upsetting the disc it was observed that core material flowed out to middle axis. The highest material flow appears at the highest reduction value of the sample with highest initial length (h / d = 1). The reason for this is the increase of stress at the center area of work piece and being this stress distribution not homogenous and material flow's being higher at the middle axis due to accumulation of the tension at the middle axis.

CONCLUSIONS

The paper presents experimental and mathematical approach for the bimetallic ring upsetting. The material flow in the upsetting process was investigated. The copper was used as core material and aluminum was used for sleeve material. Following observations are obtained with the regard to detailed analysis and experimental results;

- It was seen that material flow modeling was in concordance with transverse sections obtained after experiments. Core material shows an outer flow at the

middle axis. With higher h / d rate the deformation clearly concentrates at the middle axis.
- It is seen that on the top and bottom surfaces where material makes contact with dies the material flow is low and on the middle axis the material flow is high because of there is no contact.
- Owing to aluminum and copper are soft materials and have high plasticity, it can be seen that flow profiles are similar and because of this reason no separate on the core / sleeve material interfaces occurs.
- Based on data obtained from the model it was determined that the model gives a product profile and material flow in concordance with experiments and because of this reason this model can be used for future studies which will be performed with different process parameters.

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