

# Upsetting of Tri-Metallic St-Cu-Al and St-Cu60Zn-Al Cylindrical Billets

Isik Cetintav, Cenk Misirli, Yilmaz Can

**Abstract**—This work investigates upsetting of the tri-metallic cylindrical billets both experimentally and analytically with a reduction ratio 30%. Steel, brass, and copper are used for the outer and outmost rings and aluminum for the inner core. Two different models have been designed to show material flow and the cavity took place over the two interfaces during forming after this reduction ratio. Each model has an outmost ring material as steel. Model 1 has an outer ring between the outmost ring and the solid core material as copper and Model 2 has a material as brass. Solid core is aluminum for each model. Billets were upset in press machine by using parallel flat dies. Upsetting load was recorded and compared for models and single billets. To extend the tests and compare with experimental procedure to a wider range of inner core and outer ring geometries, finite element model was performed. ABAQUS software was used for the simulations. The aim is to show how contact between outmost ring, outer ring and the inner core are carried on throughout the upsetting process. Results have shown that, with changing in height, between outmost ring, outer ring and inner core, the Model 1 and Model 2 had very good interaction, and the contact surfaces of models had various interface behaviour. It is also observed that tri-metallic materials have lower weight but better mechanical properties than single materials. This can give an idea for using and producing these new materials for different purposes.

**Keywords**—Tri-metallic, upsetting, copper, brass, steel, aluminum.

## I. INTRODUCTION

UPSETTING is one of the basic forming processes in the manufacture world. The upsetting of single materials, such as steel, copper, aluminium, was examined by many researchers both theoretically and experimentally over four decades. Vilotic et al. [1] gave particular attention to the process of upsetting of cylindrical billets. As known, due to their different properties bi-metallic materials were used especially in marine industry, chemical industry, and electrical equipment. For example, bimetallic materials provide corrosion resistance and better conductivity, if necessary. Bimetallic materials can also be assumed as model material with volumes of different chemical compositions. For example, dual-phase material, materials with impurities, and materials with different grain size show different plastic deformation characteristics. On the other hand, bimetallic materials are different from composite materials. In composite materials, reinforcing elements almost spread uniformly in the matrix materials. But in bimetallic materials, second metal is

gained in some position of the matrix material. Plancak et al. [2] elaborated cold upsetting of dual-material component which consists of an outer ring and inner solid cylinder. Also Plancak et al. [3] analyzed the process of joining of two bimetallic axisymmetric components from various materials by upsetting bimetallic components in a closed die. Essa et al. [4] examined the behaviour of bi-metallic components during the cold upsetting process. Zhang and Dean [5] presented a mathematical model which provides a basic description of the force and displacements arising in multi-stage forging on a mechanical press. Senthilkumar and Narayanasamy [6] evaluated some of the cold-forging features of composite steel preforms of varying titanium carbide contents during cold upsetting under triaxial stress state conditions. Chang and Lin [7] investigated the effects of grain size and temperature on the micro upsetting of copper in a specialized metal forming system. Cora et al. [8] investigated the effect of friction in cold forging operations using different friction models. Chang and Bramley [9] investigated the determination of the heat transfer coefficient at the workpiece-die interface for the forging process. Thaheer and Narayanasamy [10] studied the barreling effect of truncated cone billets of various materials. Dyja et al. [11] worked on the theoretical and experimental analysis of rolling of bimetallic Cu-Al and Cu-Steel rods. Kocanda et al. [12] examined the contact pressure distribution in upsetting of compound cylindrical and cubic metals.

In this work, designing and then upsetting of tri-metallic cylindrical billets producing using different metallic materials was studied by performing experiments and FE simulations. The aim of this work was to investigate designing of tri-metallic materials and possibility of production of them via upsetting process.

## II. EXPERIMENTAL WORK

Two models have been considered for this work to show the behaviour of different materials. Basic design of Model 1 and Model 2 are shown in Fig. 1.

After the preparation of all metals in the lathe machine with the appropriate dimensions, the inner core (aluminum) was pressed by low pressure into outer ring material (copper and brass) as the first step. These parts were called bi-metallic materials [4]. Then, these bi-metallic parts were pressed in the steel outmost core with the same process. The produced multimetallic components are shown in Fig. 2. Also, the single parts which form the trimetallic parts were shown in Fig. 3.

Isik Cetintav is with Trakya University, Edirne, Turkey (phone: +905446713557; e-mail: isikcetintav@trakya.edu.tr).

Cenk Misirli and Yilmaz Can are with Trakya University, Edirne, Turkey (e-mail: cenkm@trakya.edu.tr, ycan@trakya.edu.tr).

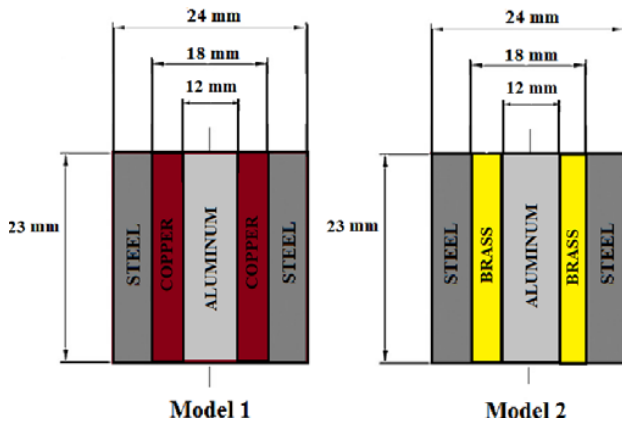


Fig. 1 Design of Multi-metallic Material Models

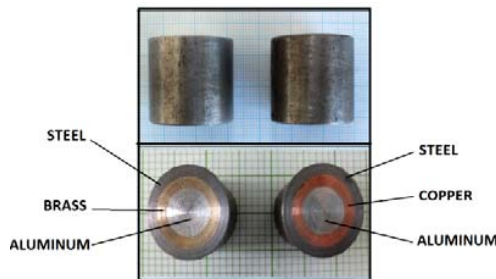


Fig. 2 Produced Tri-metallic Components

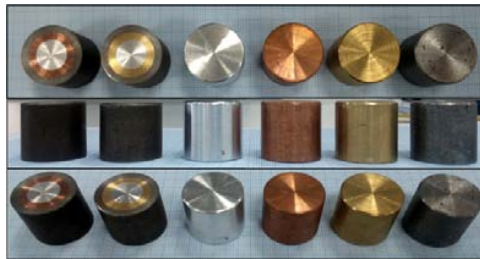


Fig. 3 Produced Models and Single Metals

TABLE I  
WEIGHT OF MATERIALS FOR GIVEN DIMENSIONS

Material	Weight(gr)
Steel	83
Copper	94
Brass	88
Aluminum	30
Model 1	70
Model 2	67

Fig. 4 shows hydraulic press of 60 tons press in which the experiments were carried out. It has a constant speed of 0.1 mm/s. The hydraulic press was equipped with a pressure current transducer in order to measure and record the experimental load. The pressure or load value was read by an I/O card of the personal computer during the experiment. This value was converted into a resistance value, then this resistance value and the pressure value were provided as an input to the software.



Fig. 4 Hydraulic Press and fixation of parts

A special lubricant named  $\text{MoS}_2$  used, specimens and flat dies were sanded and cleaning with alcohol before the experiments. The fixation of components to hydraulic press is also shown in Fig. 4. Then multi-metallic components were forged with reduction ratio 30%.

### III. FE MODEL

In order to validate the experimental work, a simulation model was designed by using finite element software. FE models of the work are employed by using ABAQUS/Implicit, CAPX8R mesh type of 8-node quadratic axisymmetric elements was used. Friction coefficient is specified as 0.1 between parts and die interfaces for each FE model, and zero friction assumed at the outmost-outer-core interface. It is assumed that contact type is surface to surface for each location. All models are axisymmetric with nodal points on the left-hand edge constrained to move along the central axis. Due to symmetry, half of the billet section is used in the model. The upper rigid die translates vertically down imposing deformation on the model which rests on a rigid, stationary, lower die.

### IV. RESULTS AND DISCUSSION

Designing, producing, upsetting and electrical conductivity of tri-metallic materials have been examined experimentally and simulated by using FE software. Fig. 5 shows the sample in the 30% reduction ratios. After reduction, samples were cut and barrel profiles of the all the three materials were observed. As it is seen from Fig. 5, there is no perceptible difference in the shape of outer barrel profile of bimetallic sample compared to upsetting of single material. A barrel curvature normally occurs due to friction at the top and bottom of the die/material interface in cylindrical billets of single materials. The profile of the barreled specimens can be generally assumed as an arc of a circle in the literature.

The meridional part of core material flows very fast, and the barrel profile is different from an arc of a circle. Barreling profile of core material is different from barreling profile of sleeve material. It is also seen from Fig. 5 that there is a no contact between two materials and a void occurred in the inner meridian part of sleeve material, as a center bust, seen in extrusion. This could explain that the inhomogeneous deformation occurs in the centerline and this void is attributed to a state of hydrostatic stress.

Fig. 6 shows the separation of single materials from tri-metallic materials after 30% reduction. As seen from the

figure, inner materials stuck on the outer materials during the forming.

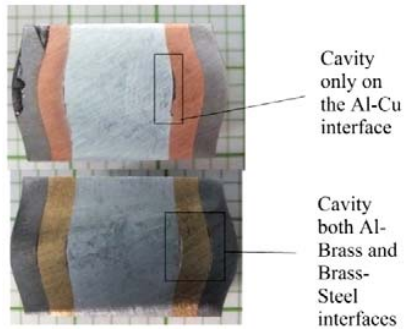


Fig. 5 Deformations, barreling, and cavities after 30% reduction

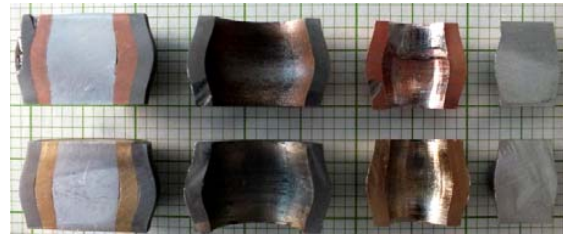


Fig. 6 Separated Conditions of Materials after 30% reduction

Fig. 7 shows the experimental force-reduction change during the forming both single materials and tri-metallic models, and it is clearly seen that steel required higher force than the others as a single material. Model 2 with brass has bigger forming force than Model 1 with copper.

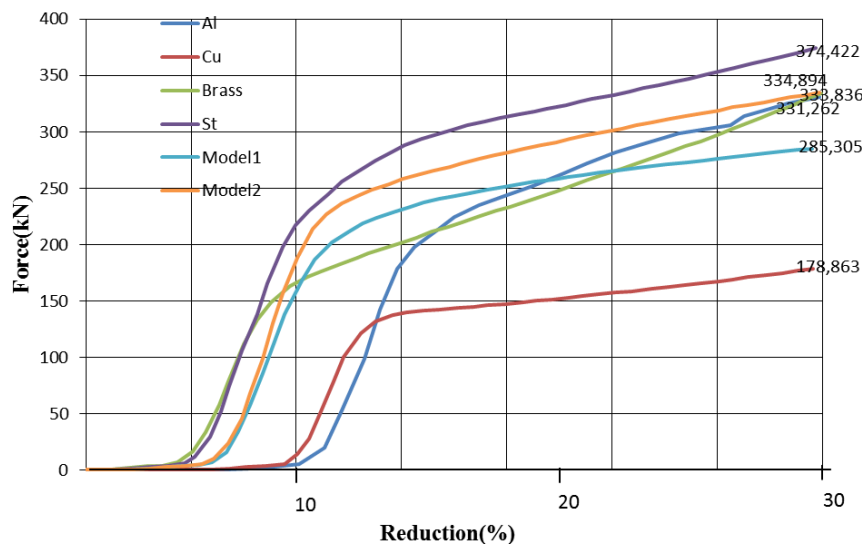


Fig. 7 Force-Reduction Graph of Single and Tri-metallic Materials

Fig. 8 shows the comparison of experimental procedure with FE simulation. Flow character of tri-metallic materials in FE simulation is the same as experimental procedure. This gives an idea to improve this research with simultaneously.

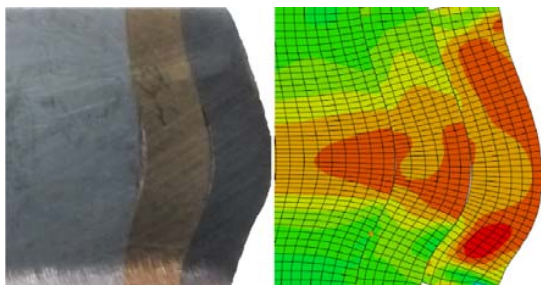


Fig. 8 Comparison of FEM calculation and experimental procedure

#### V. CONCLUSION

- It is observed that metal flow shows inhomogeneity especially for the core material. It is also guessed that the volume of core material or outer and outmost rings

materials affects the amount inhomogeneity of deformation and load requirement.

- The shift of outer, outmost and core materials also affects the metal flow and load requirement. Since the deformation behavior of tri-metallic materials is more complicated in comparison with single material, it is planned to do further work by changing the volume of outmost, outer rings and core material to investigate metal flow and workability.

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#### REFERENCES

- Vilotic, D.; Vujovic, V. & Plancak M. (1992). *Analysis of Upsetting of Cylinder by Conical Dies*. Journal for Technology of Plasticity. Vol., 17 (1-2), pp. 67-72.
- Miroslav Plancak, Igor Kacmarcik, Dragiša Vilotic, Marko Krsulja (2012). *Compression of bi-metallic components-analytical and*

- experimental investigation*, International Journal of Engineering. 1584-2665.
- [3] Miroslav Plančak, Zlatan Car, Dragiša Vilotić, Dejan Movrin, Marko Kršulja (2011). *Upsetting of bimetallic components in a closed die*. Engineering Review Vol. 31, Issue 2, 105-109.
- [4] K. Essa, I. Kacmarcik, P. Hartley, M. Plancak, D. Vilotic (2011). *Upsetting of bi-metallic ring billets*. Journal of Materials Processing Technology. 212 817–824.
- [5] Zhang, H.G., Dean, T.A., (1995). *Interaction of process and machine in multi-stage forging on a mechanical press*. Part B: Journal of Engineering Manufacture. Proc Instn Mech Engrs Vol 209, 19-32.
- [6] Senthikumar, V., Narayanasamy, R., (2008). *Influence of titanium carbide particles addition on the forging behaviour of powder metallurgy composite steels*. Proc. IMechE Vol. 222 Part B: J. Engineering Manufacture, 1333-1345.
- [7] Chang, C. C., Lin, J. C., (2010). *Influence of grain size and temperature on micro upsetting of copper*. Proc. IMechE Vol. 226 Part B: J. Engineering Manufacture, 183-190.
- [8] Cora, Ö. N., Akkök, M., Darendeliler, H., (2008). *Modelling of variable friction in cold forging*. Proc. IMechE Vol. 222 Part J: J. Engineering Tribology, 899-908.
- [9] Chang, C. C., Bramley, A. N., (2002). *Determination of the heat transfer coefficient at the workpiece-die interface for the forging process*. Proc Instn Mech Engrs Vol 216 Part B: J Engineering Manufacture. 1179-1186.
- [10] Thaheer, A. S. A. & Narayanasamy, R. (2007). *Barrelling in truncated lubricated zinc cone billets during cold upset forging*. Materials & Design. Vol., 28, pp. 434-440.
- [11] Dyja, H., Mroz, s. & Milenin, A. (2004). *Theoretical and experimental analysis of the rolling process of bimetallic rods Cu-steel and Cu-Al*. Journal of Materials Processing Technology. Vol. 153-154, pp. 100-107.
- [12] Kocanda, A.; Presz, W.; Adamczyk, G.; Czyzewski, P. & Mazurek, W. (1996). *Contact pressure distribution in upsetting of compound metals*. Journal of Materials Processing Technology. Vol., 60, pp. 343-348.