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THEORETICAL ANALYSIS OF METAL FLOW VELOCITY OF BIMETALLIC ROD DURING EXTRUSION PROCESS

The paper analyses theoretical aspects of metal flow velocity in bimetallic rods during extrusion processes. Flow velocities of bimetal for particular layers were analyzed with application of the ExtrBim Model and the Forge2 commercial software. The metal flow velocities of particular layers were analysed for different parameters.

Проведен анализ теоретических аспектов скорости пластической деформации металла биметаллических катанок при экструдировании. Скорость деформации биметаллов в определенных слоях анализируется с использованием модели ExtrBim и промышленного программного обеспечения Forge2. Скорости пластической деформации металла в определенных слоях проанализированы в соответствии с различными параметрами.

Introduction

The extrusion process has been known for a long time. It is a deformation process used to produce long, straight, semi-finished metal products such as rods, solid and hollow sections, tubes, wires and strips. In extrusion process under a high pressure, a billet is squeezed from a container through a die to obtain a proper reduction. Extrusion can be carried out at room temperature or at high temperatures, depending on the alloy and the method [1]. There are three main methods of the extrusion in depending on direction of metal flow and die motion: direct extrusion, indirect extrusion and mixed extrusion.

During direct extrusion metal is closed in container and forced to pressure of steam and dummy block (1,2 in Fig.1) flowing through the die (5 in Fig.1) and reducing cross-section taking a shape from sizing part of the die (c zone in Fig.1).

Metal is deformed in non-uniform way during the direct extrusion due to existing high friction forces on container and die wall and deformation characteristic of the process. The highest velocities of metal flow have middle layers of billet and the lowest velocity appears in peripheral zones of the billet.

Aim of the research

Analysis of flow velocities of bimetal for particular layers was carried out with using model ExtrBim described in works [2] and model of commercial software Forge2 [3]. The metal flow velocities of particular layers were researched for different parameters. Half conical die angle (α) varies from 15° to 45° and extrusion ratio (λ) varies from 2 to 10.

Discussion and conclusions

In Fig.2 the distribution of velocity components V_r i V_z on the boundary between core and sleeve of bimetal rod in deformation zone

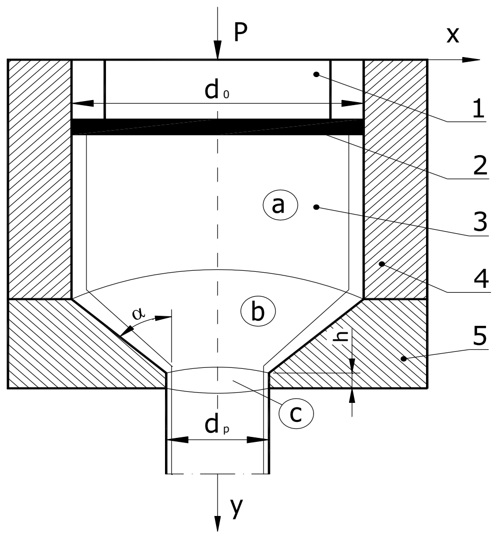

Fig.1. Schema direct extrusion of bimetal billet, 1 – steam, 2 – dummy block, 3 – billet, 4 – container, 5 – die; a – deformation zone in container, b – deformation zone in die, c – sizing zone; d_0 – initial diameter of billet, d_p – final diameter, α – half conical die angle, h – high of sizing zone

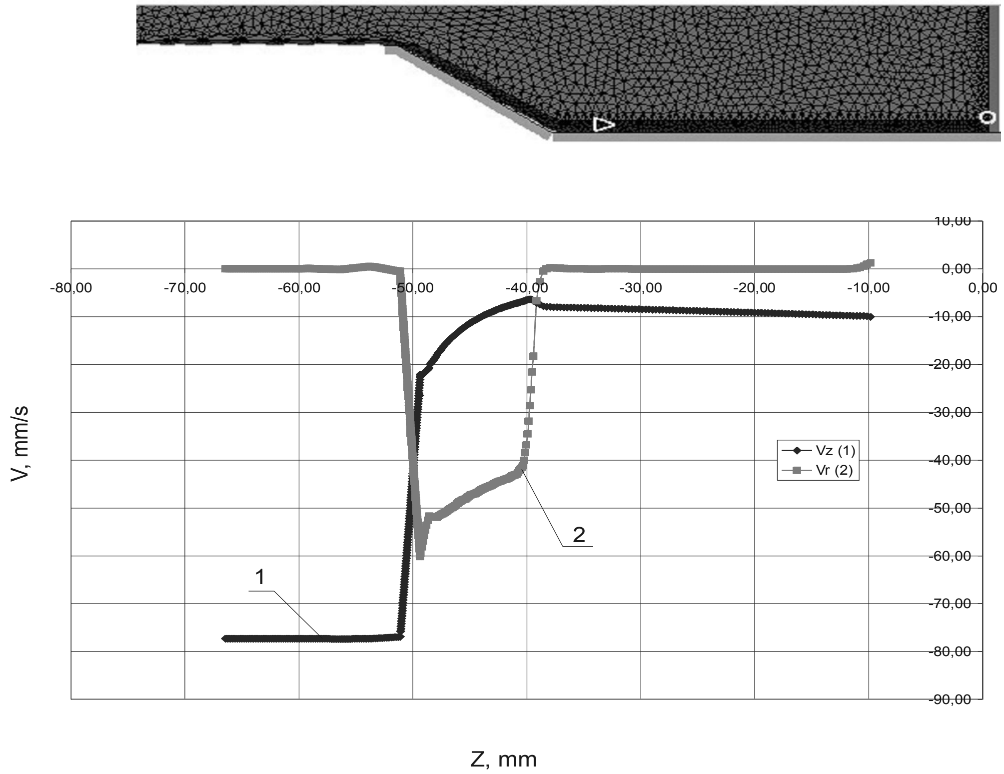

Fig.2. Changing the values of longitudinal V_z velocity component radial V_r during the bimetallic extrusion of Al/Cu rod in the contact zone between die and billet (FORGE2 model)

was shown. Presented distribution of velocities was registered for contact layer between billet and container wall. Curve 1 represents values of longitudinal velocity component whereas curve 2 represents values of radial velocity component, in dependence on coordinate z. From data presented in Fig.2. it can be stated that radial velocity component V_r appears on entry to deformation zone (zone b Fig.1). The highest values of radial velocity component V_r appears on the boundary between sizing zone and deformation zone. For case showed in Fig.2 The values V_r equal above 60 mm/s, whereas value of longitudinal velocity component V_z, according to constancy-of-volume relationship, into the deformation zone rises, until steady-state after an output from the die (in Fig.2 the steady state value of velocity equal about 78 mm/s).

In Fig.3 a÷d the distribution of values of longitudinal velocity component V_z of bimetal billet in the deformation zone were presented. In figures 3 a÷d three curves were presented – axial cross-section (curve 1), in the boundary of bimetal layers (curve 2) in the boundary between billet and die (curve 3) in dependence on coordinate *z* (along the axis of extrusion).

In Fig.3 the distributions were obtained for extrusion in die with $\alpha = 15°$. How it can be stated from data presented in this figure, using a die with low value of die angle α causes significant elongation of deformation zone. The length of the zone vary from 8 mm for $\lambda = 2$ to 20 mm for $\lambda = 10$. The example length of particular zones of deformation were show in Fig.3.

It can be seen from data presented in Fig.3, that the highest differences between values of velocity in billet axis (aluminium core), and values of velocity of boundary layer (cladded copper layer) vary in range from 22,8 mm/s (for extrusion ratio $\lambda = 10$) to 4,1 mm/s (for extrusion ratio $\lambda = 2$). The highest differences between the values of velocity (in axial and boundary zones) is located on plane placed in distance 5÷10 mm from cross-section in sizing part of die. It should be noticed that the place with the highest difference in velocity component (curves 1÷3) depends on used extrusion ratio. Therefore for $\lambda = 10$ (Fig.3 a) it is about ¾ distance between a/b plane (in entry to plas-

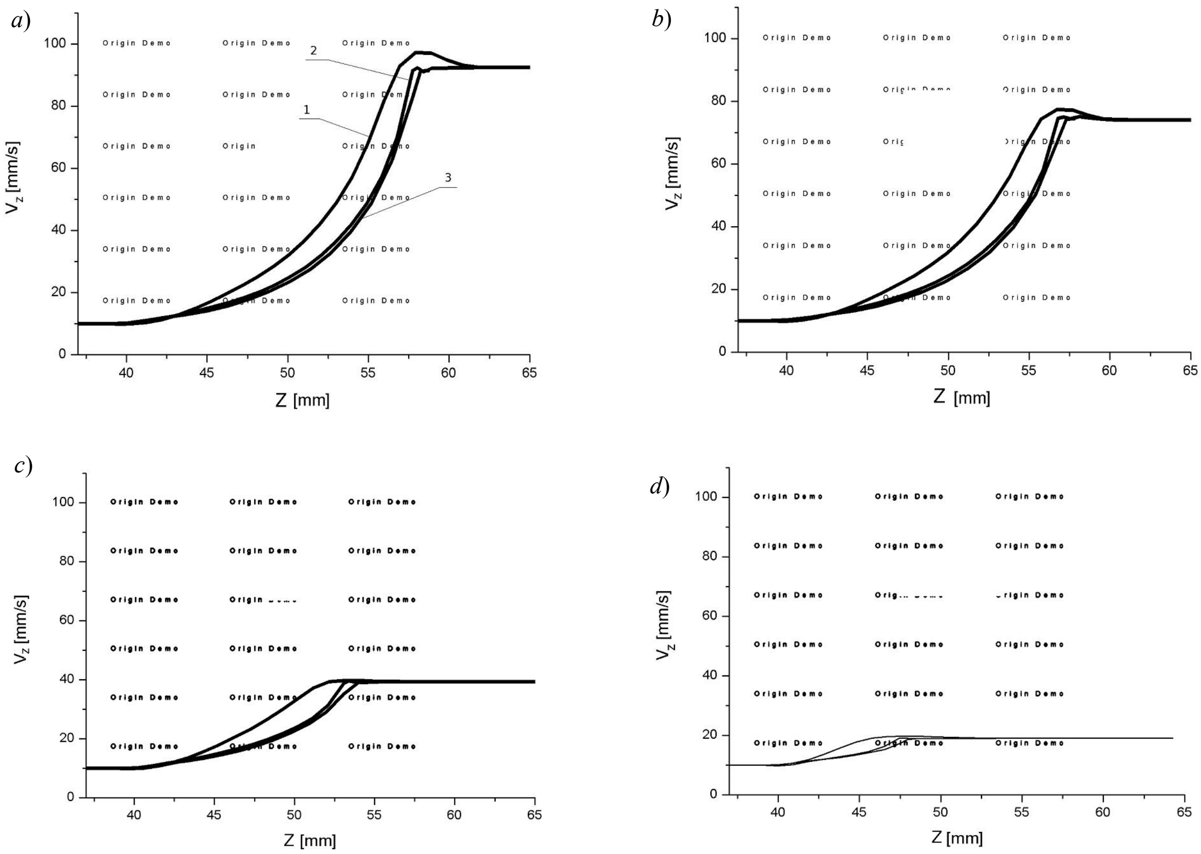

Fig.3. Velocity of bimetal flow in billet axis (1), in the boundary of layer contact (2) and in the surface of contact between billet and layer (3), with half die angle α = 15°, with extrusion ratios: *a*) λ = 10, *b*) λ = 8, *c*) λ = 4, *d*) λ = 2

tic deformation zone) and b/c plane (in exit from die), whereas for λ = 2 (Fig.3 d) the difference is located half distance between those planes.

Using a die with higher half die angle α = 20° causes increase differences between velocity components of layers for specified places of bimetal from 34,2 mm/s for λ = 10 to 4,52 mm/s for λ = 2. It is necessary to state that for that case, in comparison to the die with α = 15°, a proportional contraction of plastic deformation zone, which the length for λ = 10 equals about 15 mm.

Continuation of increasing the die angle (α = 25° and α = 30°) provides to increasing the non-uniform velocity flow in axial layer and in the boundary of joining core with sleeve, in this cases value ΔV for λ = 10 is about 41,49 mm/s, and for λ = 2 is 4,61.

From data presented in Fig.3a÷d it can be observed lower inclination of the curves 1, 2 and 3 to the axis Z that is caused by contraction of zone b (Fig.4), which effected a significant increase of differences between the flow velocities of axial layers and boundary layers. The differences in velocities are contained in range: 50,72÷60,37 mm/s for λ = 10 and 6,57÷10,26 mm/s for λ = 2.

During the extrusion of bimetal non- uniformity of flow velocity increases according to billet entering to die zone (in Fig.4 zone b). After passing through the die (in Fig.4 plane – a/b) component of bimetal velocity is the same as for both layers of bimetal on whole cross-section.

For investigated cases the function depends on the highest differences between velocities in axis of bimetal and in the boundary of joining bimetal layer ΔV, and on the extrusion ratio λ and die angle α.

$$\frac{\Delta V}{V_0} = -1{,}9821 + 0{,}1206 \cdot \alpha + 0{,}1879 \cdot \lambda + + 0{,}002 \cdot \alpha^2 + 0{,}0103 \cdot \alpha \cdot \lambda - 0{,}0021 \cdot \lambda^2.$$

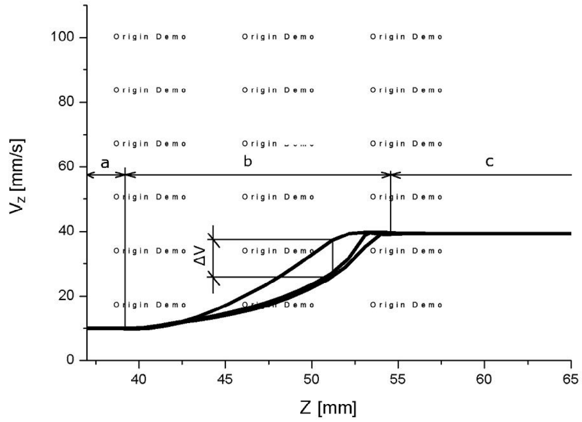

Fig.4. Distribution of velocity for different zones of deformation (a, b,c) and maximal difference between values of velocity (ΔV) for case $\alpha = 15°$ and $\lambda = 4$; a/b plane in entry to plastic deformation zone, b/c – plane in exit from die

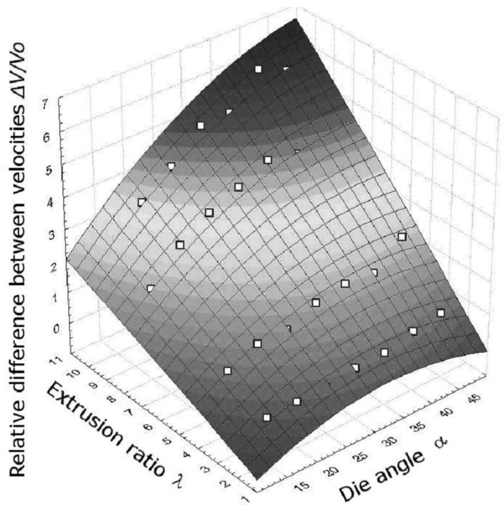

Fig.5. Relationship between the extrusion ratio λ and die angle α and maximal differences in velocities in axis, and velocities in boundary layers

In Fig.5 The graphical presentation of the relationship.

From the data presented in Fig.5 it can be stated that the highest differences between velocities were observed for maximal values of parameters λ and α. Furthermore higher influence on differences in velocities has extrusion ratio λ.

Also it could be stated that increasing die angle, with the same extrusion ratio λ increases non-uniformity of bimetal billet flow. Moreover, the characteristic perturbations of changing the direction of velocity vectors in the boundary of bimetallic layers, which are caused by influence of outer layer (with higher resistant to flow – Cu) on inner layer (Al). Copper layer, because of the friction forces of working part of die, have smaller deformations than axis layers. Smaller deformation of outer layer is compensated in working part of die where the layer, according to constancy-of-volume relationship, intensively starts to flow.

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