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THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE Cu-Al BIMETALLIC BAR ROLLING PROCESS

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In this study, the authors present the results of their theoretical and experimental analysis of the rolling process of Cu – Al bimetallic bars in elongation passes. The original bars were round aluminium bar, covered with copper layer. For theoretical tests, the Forge2008® computer program was used, based on FEM. The model simulated metal flow during rolling of bimetallic bars in oval – round passes. The results of the experiments were compared with the finite element calculations. The analysis demonstrated that an appropriate selection of shape and size of oval pass allows production of even distribution of the copper layer in the bimetallic roll products.

Key words: bimetallic bars, elongating grooves, FEM (Finite Elements method), numerical analysis

Teoretska i eksperimentalna analiza Cu-Al bimetalnih šipki u procesu valjanja. O ovom su radu autori prezentirali rezultate teoretske i eksperimentalne analize procesa valjanja Cu-Al bimetalnih šipki pri istezanju. Originalne šipke su bile okrugle aluminijske šipke, sa bakrenim zaštitnim slojem. Za potrebe teorijskog istraživanja korišten je program Forge 2008, koji je baziran na MKE. Model simulira tečenje metala za vrijeme valjanja bimetalnih šipki u kružnim prolazima. Rezultati eksperimenta su uspoređeni s proračunom konačnih elemenata. Analiza pokazuje kako odgovarajući izbor oblika i veličine kružnog prolaza dopušta proizvodnju ili čak razdiobu bakarnog sloja na bimetalnim valjanim proizvodima.

Ključne riječi: bimetalne šipke, žljebovi izduženja, MKE (Metoda konačnih elemenata), numerička analiza

INTRODUCTION

Predicting three-dimensional metal flow during groove-rolling of bimetallic bars is one of the fairly complex tasks facing the engineer when working out a new roll pass design [1]. The knowledge of the characteristics of shape variation of billet being rolled (such as widening and elongation) alone is nor sufficient for performing correctly a roll pass design and developing a correct groove-rolling technology. The theoretical determination of local velocity fields and the uniqueness of rolled billet flow within the whole roll gap volume, while considering billet shape and temperature, rolling speed, the rheological properties of the metal and friction conditions on the metal-to-roll contact surface, has made it possible to speed up considerably the development of an industrial rolling technology and reduce the cost and time consuming of tests needed during practical starting up of the manufacture of new products in a groove-rolling mill.

Computer modelling is the cheapest of the possible ways of process analysis and, at the same time, it provides a huge amount of information impossible to be acquired by other methods. The purpose of carrying out computer simulations is the verification of technologies being designed for bars of different shapes and of different materials in the real technical conditions of a rolling mill, prior to their implementation.

By applying computer programs relying on the finite element method to solving plasticity-theory tasks within the design of bar groove-rolling process technologies, the number of laboratory and industrial tests can be limited to an indispensable minimum [2-5]. In the present study, the Forge2008® was used for the analysis of plastic metal flow in stretching passes [6, 7].

MATHEMATICAL MODEL OF FORGE 2008® COMPUTER PROGRAM

The thermo-mechanical simulation of the groove-rolling process was carried out with the use of a visco-plastic model in the triaxial state of strain by using the Forge2008® program, whereas the properties of the deformed material were described according to the Norton–Hoff [6, 7] conservation law written in the following form (1):

$$S_{ij} = 2K_0(\varepsilon + \varepsilon_0)^{n_0} \cdot e^{(-\beta_0 \cdot T)} (\sqrt{3\dot{\bar{\varepsilon}}})^{m_0 - 1} \dot{\varepsilon}_{ij}, \qquad (1)$$

where: s_{ij} is the deviatoric stress tensor, $\dot{\bar{\varepsilon}}$ is the equivalent strain rate, $\dot{\varepsilon}_{ij}$ is the equivalent strain rate tensor, ε –

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equivalent plastic strain, ε_0 – base strain, T is the temperature, K_0, m_0, n_0, β_0 represent materials constants

CONDITIONS ADOPTED FOR COMPUTATIONS

The application of the computer program Forge2008® using the thermo-mechanical models that it contains requires the definition of boundary conditions which are decisive to the correctness of numerical computation. The properties of the aluminium and copper examined, friction conditions, and the kinetic and thermal parameters describing the rolling process.

Bimetallic bars with an outer diameter of 21,7 mm covered with 2,8 mm copper layer, after explosive welding [8-9], were rolled on a D 150 two-high shape mill. The stock material was round PA6 (according to the Polish standard) aluminium bar covered with an M1-E (according to the Polish standard) copper layer. Heating of the bimetallic stock of an initial length of 250 mm was carried out in a chamber furnace. Bars heated up to a temperature of 400 °C. Rolling speed was approx. 0,45 m/s. As a result of rolling in 2 passes (oval-round), bars of a diameter of about 18,0 mm were obtained. During rolling, the copper layer thickness decreased by 0,5 % compared with bars after explosive welding. All passes were investigated using theoretical and experimental methods.

The theoretical analysis was performed for the real rolling conditions: the working roll diameter D = 150 mm, coefficient of friction – 0,3, coefficient of heat exchange between the material and the tool, α – 3000 [W/Km^2]; coefficient of heat exchange between the material and the air, α_{air} – 100 [W/Km^2], tool temperature – 60 °C; ambient temperature – 20 °C.

The junction between the core and the cladding layer was defined as closely fitting. The nodes of both grids were shared.

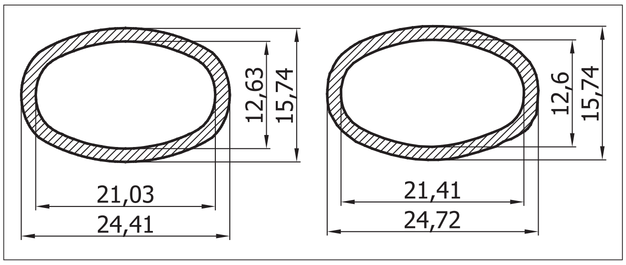
RESULTS AND DISSCUSION

An experimental and a theoretical analysis of variations in the shape of bars during groove-rolling were carried out in the study. Simulations of rolling were performed to verify the accuracy of prediction of the shape and dimensions of band obtained in the passes. The obtained computation results were compared with the templates taken after rolling in a particular pass. The view of all cross-sections is shown in Figure 1.

From the data shown in Figure 1 it can be seen that as a result of rolling bimetallic strip in the oval and round passes an 18 mm-diameter bimetallic bar was obtained. The properly selected rolling parameters enabled a copper-aluminium bimetallic bar to be produced without any delamination at the bond boundary and with a uniform distribution of the clad layer over the bimetallic bar perimeter and length.

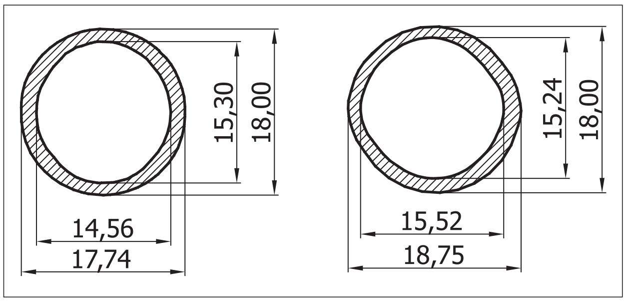
a) b) c)

Figure 1 View of lateral samples taken from the billet after rolling in particular passes: a) billet, b) 1st pass, c) 2nd pass.



a) b)

Figure 2 Comparison of theoretical – a) and experimental – b) shapes and dimensions of bimetallic bars (copper–aluminium) after first pass.



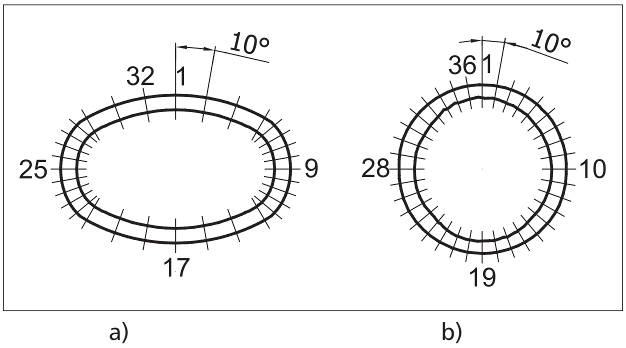
a) b)

Figure 3 Comparison of theoretical – a) and experimental – b) shapes and dimensions of bimetallic bars (copper–aluminium) after second pass.

Figures 2-3 show comparison of the shape and dimensions of the strip and the bimetallic bar obtained from numerical modelling and experimental tests.

It can be seen from the data shown in Figures 2-3 that the shape and dimensions of the Cu-Al bimetallic strips obtained from computer simulations are consistent with the shape and dimensions of the passes used and the shape and dimensions of the templates taken after rolling. In none of the cases was any difference noticed between the pass height and the strip height obtained from simulations and experimental tests. The differences between the strip widths obtained as a result of simulations and the strip widths obtained from the rolling process were negligible. For the first pass (the circle-oval pass), the difference in width was 0,3 mm (Figure 2), while for the second pass (the oval-circle pass) the difference amounted to approx. 1,0 mm (Figure 3). In none of the passes did any pass overfill occur.

Also the geometrical parameters of the cross-sections of bimetallic bars obtained from numerical modelling and experimental tests were examined in the study. A sche-



a) b)

Figure 4 Schematic of measurements of clad layer distribution after rolling: a) in the oval pass, b) in the round pass.

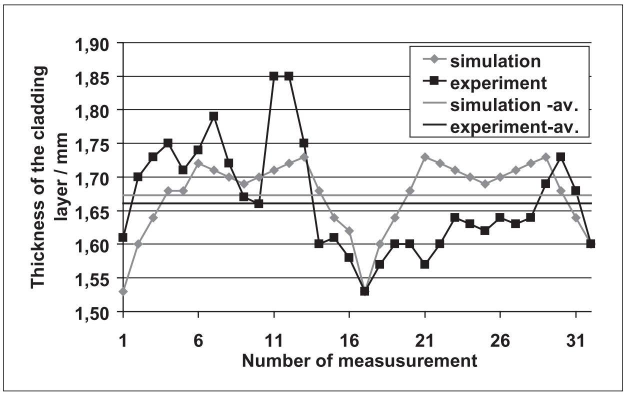


Figure 5 Distribution of Cu layer thickness over the aluminium core after the first pass.

matic of the taking of measurements of the distribution of the clad layer over the Al core is shown in Figure 4.

In order to determine the distribution of copper layer height over the aluminium core, 32 measurements were taken for strips obtained during rolling in the oval pass and 36 measurements for strips obtained from the round pass. Examinations were carried out both for strips obtained from numerical modelling, as well as for strips obtained as a result of experimental tests. Measurements were taken every 10 °.

Figures 5 and 6 show the distribution of copper layer thickness over the aluminium core perimeter.

When analyzing the data shown in Figures 5 and 6, an uneven copper layer thickness distribution can be observed over the whole aluminium core perimeter. The greatest "thinning" of the copper layer is noticed in the vertical axis of the strip, whereas the greatest "thickening" of the copper layer – in the horizontal strip axis. This copper layer distribution over the aluminium core can be explained by a slight flowing of the clad layer from the bar core towards the strip width. The presented results of numerical computations and experimental tests indicate that the copper layer moves along the lateral strip sides during groove-rolling, so also relative to the roll groove surface, which is consistent with the investigation results provided in work [10, 11].

The average copper layer thickness values obtained from numerical computations and from experimental tests were similar. The relative error did not exceed 1,2 %.

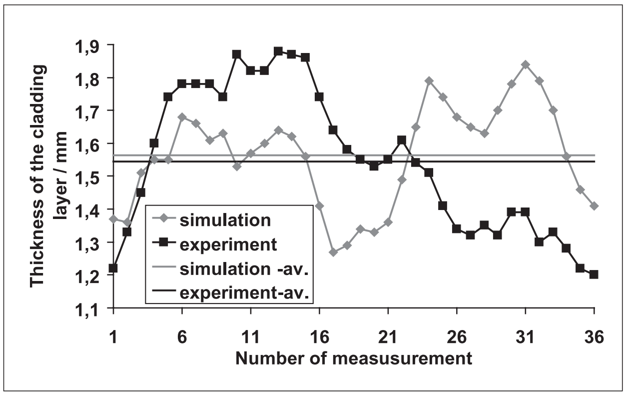


Figure 6 Distribution of Cu layer thickness over the aluminium core after the second pass.

The difference between the maximum value of copper layer thickness for the first pass (Figure 5) amounted to 0,2 mm for the numerical modelling results and 0,32 mm for experimental test results. For the second pass (Figure 6), on the other hand, the differences in copper layer thickness were greater, amounting to 0,57 mm for the numerical modelling results and 0,68 mm for the experimental test results.

SUMMARY

The investigation carried enables the following observation to be made and conclusions to be drawn:

1. Good agreement between the shape and dimensions of bimetallic bars obtained from numerical computations and experimental tests was obtained.
2. The distribution of copper layer thickness over the perimeter of the aluminium core was determined. As a result of the groove-rolling of bimetallic bars, a displacement of the clad layer towards the roll groove follows, which results in an uneven distribution of the clad layer over the bimetallic bar perimeter.
3. Computations carried out for the conditions of bimetallic bar rolling have shown that the model accurately reflects the conditions of rolling in elongation grooves. A correctly performed rolling process assures the bimetallic bar product to be obtained with bonding quality comparable with a stock material after explosive welding.

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Note: The professional translator for English language is Czes³aw Grochowina, Studio-Tekst, Poland.