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ISSN 0543-5846
METABK 42 (4) 261-264 (2003)
UDC - UDK 621.771-419.4=111

THE PREDICTION OF CURVATURE OF BIMETALLIC PLATE Al-Cu DURING ASYMMETRICAL COLD ROLLING

Received - Primljeno: 2002-05-02
Accepted - Prihvaćeno: 2003-02-25
Review Paper - Pregledni rad

In the paper, solving a problem of rolling Al-Cu plates by the numerical way is presented. In the development of new technologies in rolling of bimetallic plates there are many problems both with ensuring a uniform strain distribution and producing a straight plate as well. Such a solution within research of the numerical simulation was obtained at the Forge 2 program based on finite element method. The cold rolling process was carried out at the temperature of 20 °C for 10 %, 20 % and 25 % relative rolling reduction. The curvature of bimetallic plate was numerically controlled by changing the speed of one roll. In this article the numerical analysis of asymmetrical rolling processes of plate composed with two metal layers, Al and Cu, has been done. At the work an influence of rotary speed ratio and value deformation on change of curvature bimetallic plate is determined.

Keywords: *bimetallic plate, asymmetrical rolling, thickness layers ratio, asymmetrical rotation speed*

Predviđanje zakrivljenosti bimetalne limene ploče Al-Cu tijekom asimetričnog hladnog valjanja. U radu je predstavljen numerički način rješavanja valjanja Al-Cu limenih ploča. U razvoju novih tehnologija za valjanje bimetalnih ploča ima mnogo problema i u osiguravanju jednolikog rasporeda deformacije i u proizvodnji ravnih ploča. U okviru provedenih istraživanja programa Forge 2, baziranom na metodi konačnih elemenata, ostvarena je numerička simulacija. Proces hladnog valjanja proveden je na temperaturi od 20 °C s relativnom redukcijom valjanja od 10 %, 20 % i 25 %. Zakrivljenost bimetalne ploče kontrolirala se numeričkim mijenjanjem brzine valjaka. U ovom članku napravljena je numerička analiza procesa asimetričnog valjanja ploče sastavljene od dva metal nasloja: Al i Cu. Također je utvrđen utjecaj omjera brzine rotacije i vrijednosti deformacije na promjenu zakrivljenosti metalne ploče.

Ključne riječi: *bimetalna ploča, asimetrično valjanje, omjer debljine slojeva, brzina asimetričnog valjanja*

INTRODUCTION

A continuous increase of demands of quality and properties of homogeneous material has caused interest in multilayer materials. The analysis of bimetallic plate production is a complex and difficult problem to solve in a theoretical way. The main reason is that layers of bimetallic band deform non-uniformly [1-6]. Variety of the strain intensity is related to different properties of bimetal components, which is strictly connected with their chemical composition. Different chemical composition of the layers influences their hardness that brings about bending of the strip due to unequal state of stress over its thickness. Industrial and a lot of experimental researches have proved that the ratio of strains in the layers can vary substantially within the range of 0.57 - 1.3 (depending on the chemical compositions of welded steels and rolling process parameters) [2]. A soft layer flows around a hard layer due to a higher degree of deformation.

AIM AND SCOPE OF RESEARCH CONDUCTED

The process of rolling Al-Cu plates both numerically and experimentally was considered in the presented paper. The conducted research was to determine the possibility to roll materials with different plasticity and melting temperature which were preliminarily explosive-welded. As the explosive welding technique does not always enable it to obtain plates of required thickness, it is necessary to roll them. The cold rolling process was carried out at the temperature of 20 °C. The numerical investigation was based on computer simulation using the Forge 2D program and the finite element method as well as the elastic-and-plastic model of

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strip strain [7]. For the correct design of the rolling process it was necessary to experimentally determine work-hardening curves as well as their equations.

The problem of friction on the stripe and rollers surface contact was simulated using the solution by Tresca:

$$\tau = -m\frac{\sigma_0}{\sqrt{3}}\frac{\Delta V}{\Delta v} \tag{1}$$

where:

τ - vector of unitary friction forces,
σ_0 - base plastifying strain,
m - friction factor,
$\Delta V/\Delta v$ - friction coefficient being 0.6 for aluminium and its alloys, and 0.55 for cooper [5].

A computer programme Forge 2D based at the finite elements method was applied. At the numerical solution elasto-plastic model was applied. Research for 10 %, 20 % and 25 % relative rolling reduction was made. Diameter of the rolls was D_w = 500 mm and the rolling speed 1.6 m/s. The bimetallic stripe thickness was 14 mm and 28 mm.

NUMERICAL ANALYSIS

The numerical investigation was carried until to the moment of getting a straight line bimetallic band. A curvature of the band authors defined as $1/R$ (where R - radius of curvature computed from the equation of circle. To avoid the defect of the band curvature authors used the asymmetrical rotation speed of the rolls, which is rotation speed of upper roll to rotational speed of lower roll ratio $a_v = V_g/V_d$.

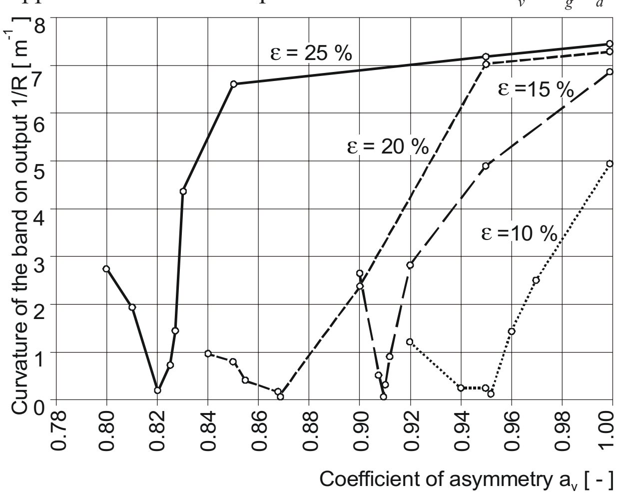

Figure 1. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of rolling reduction for H_M/H_T = 10/2**

Slika 1. **Odnos između zakrivljenosti bimetalne trake Cu-Al, brzine asimetrične rotacije i vrijednosti redukcije valjanja za H_M/H_T = 10/2**

The relation between the curvature of bimetallic band and the value of coefficient of asymmetrical rotation speed of the rolls has obtained using Forge 2D program. The results of this analysis are showed on Figures (1. - 6.).

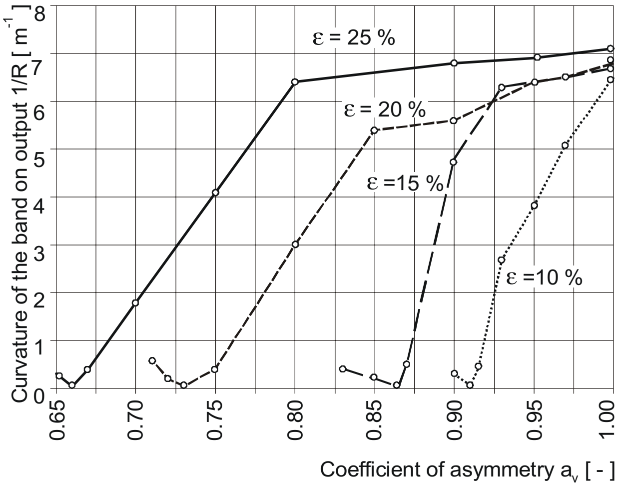

Figure 2. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of rolling reduction for H_M/H_T = 8/4**

Slika 2. **Odnos između zakrivljenosti bimetalne trake Cu-Al, koeficijenta brzine asimetrične rotacije i vrijednosti redukcije valjanja za H_M/H_T = 8/4**

The relation between the curvature of bimetallic plate and the value of coefficient of asymmetry a_v is shown on Figures (1. - 4.) for four values of rolling reduction. It was

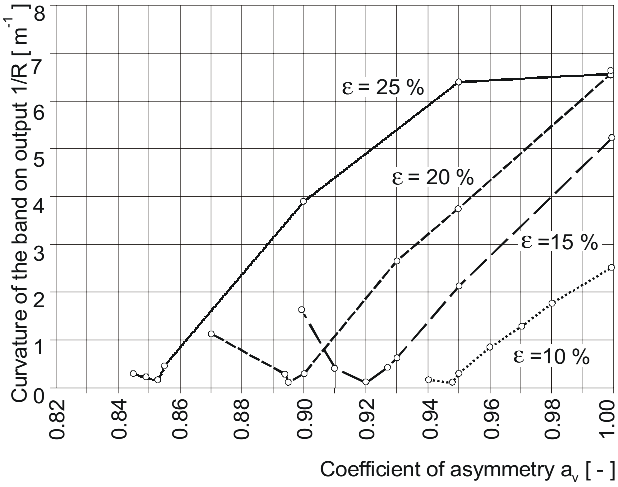

Figure 3. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of rolling reduction for H_M/H_T = 20/4**

Slika 3. **Odnos između zakrivljenosti bimetalne trake Cu-Al, koeficijenta brzine asimetrične asimilacije i vrijednosti redukcije valjan ja za H_M/H_T = 20/4**

observed that both the value of the rolling reduction and ratio of H_M/H_T and the value of the roll radius coefficient H/R_w have an influence on the relations above. The optimal value of the coefficient of asymmetry is that value, which has the lower value of the band curvature. With the increase of the hard layer fraction it is necessary to deliver the higher coefficient of asymmetrical rotational speed to set a straight line bimetallic plate. Beside the influence of the roll radius coefficient for two characteristic rolling reductions is shown a Figures 5. and 6. with all range of examined layer thickness ratios (for Al-Cu plates).

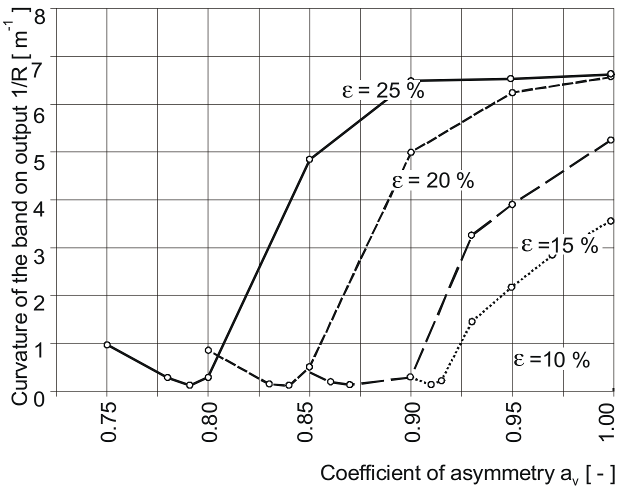

Figure 4. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of rolling reduction for H_M/H_T = 16/8**

Slika 4. **Odnos između zakrivljenosti bimetalne trake Cu-Al, koeficijenta brzine asimetrične rotacije i vrijednosti redukcije valjan ja za H_M/H_T = 16/8**

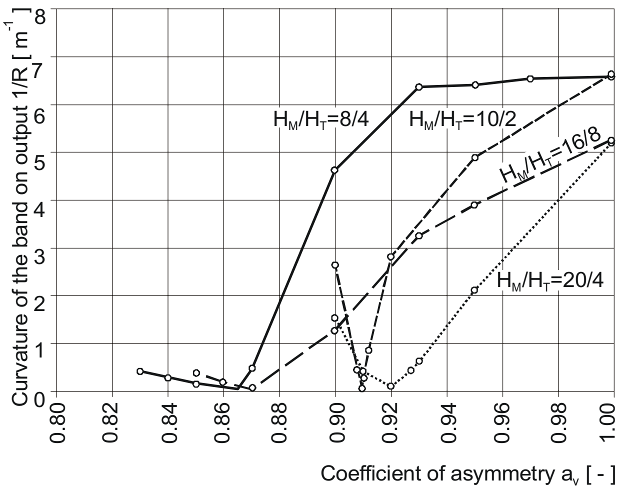

Figure 5. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of the layer thickness ratio H_M/H_T for rolling reduction ε = 15 %**

Slika 5. **Odnos između zakrivljenosti bimetalne trake Cu-Al, koeficijenta brzine asimetrične rotacije i vrijednosti omjera debljine slojeva H_M/H_T za redukciju valjanja ε = 15 %**

The minimum values of the bimetallic plate curvature for reduction ε = 10 %, 15 %, 20 % and 25 % were shown on Figures 1. - 6. and it is meant getting the straight line band on the output of the deformation zone.

On the basis of presented distributions of the bimetallic plate curvature existence of meaningful influence of the layer thickness ratio H_M/H_T and rolling reduction on the optimal value of asymmetry coefficient can be obtained. In case of higher value of hard layer fraction in total thickness of bimetallic plate (Figures 1. - 6.) the range of optimal value of asymmetry coefficient is rising. In research ranges of the rolling reduction ε = 10 - 25 % the 50 % increase of the hard layer thickness causes the increase of the range of optimal value of asymmetry coefficient a_{vopt} from 0.95 - 0.83 for H_M/H_T = 10/2 until 0.91 - 0.6 for H_M/H_T = 8/4. However the increase of hard layer thickness for bimetallic plate with H=24 mm, causes the displacement from range 0.948 - 0.853 for H_M/H_T = 20/4 to 0.84 - 0.79 for H_M/H_T = 16/8 of a_{vopt}. The increase of total thickness of bimetallic band H for the same ratio H_M/H_T brings about obtaining the straight line bimetallic band for ε > 10 % and the lower asymmetry of rotation speed of the roll (Figures 5. - 6.).

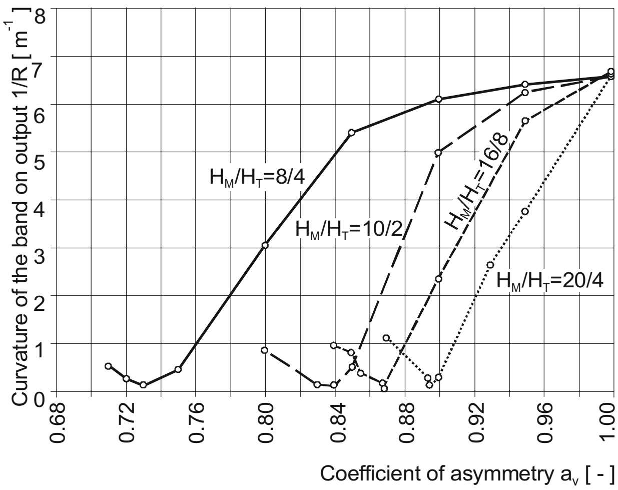

Figure 6. **The relation between the curvature of bimetallic band Cu-Al and coefficient of asymmetrical rotation speed and the value of the layer thickness ratio H_M/H_T for rolling reduction ε = 20 %**

Slika 6. **Odnos između zakrivljenosti bimetalne trake Cu-Al, koeficijenta brzine asimetrične rotacije i vrijednost omjera debljine slojeva H_M/H_T za redukciju valjanja ε = 20 %**

Increasing the value of rolling reduction ε (Figures 1. - 4.) causes the increases of the plastic flow velocity of soft layer on the output from the deformation zone. It leads to increase the curvature of the band on output from the rolling mill, i.e. the increase of plastic flow velocity of the bimetallic layers. Such effects are received by increasing the rotational speed of the lower roll contacted with hard layer. The straight line band is obtained by increasing the asymmetry of rotational speed of the roll.

It was done the laboratory testes to verify the numerical simulation. The curvature of bimetal plates have been measured for a_v =0.7 - 1.11 and constant value of relative reduction (6 %). Comparison of laboratory and numerical results had been shown in Figure 7.

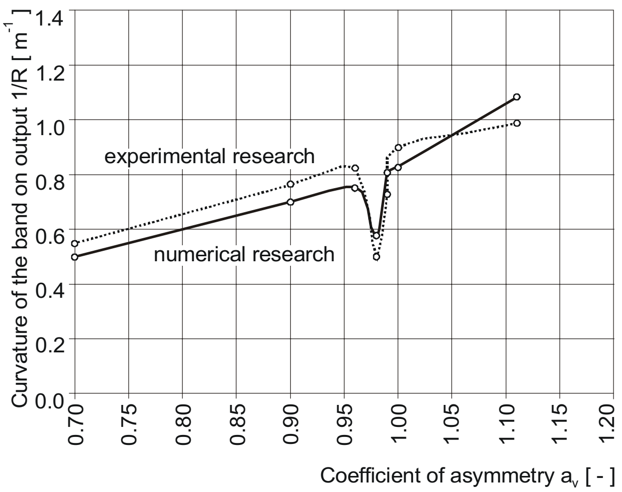

Figure 7. **The comparison of the relationships between asymmetry coefficient and band curvature, H_M/H_T = 2/12, ε = 6 % for experimental and numerical research**

Slika 7. **Usopredba odnosa između koeficijenta asimetrije i zakrivljenosti trake H_M/H_T = 2/12, ε = 6 %**

It can be stated that in whole range of asymmetry coefficient the numerical results have good compatibility with laboratory results.

CONCLUSIONS

On the basis of realized numerical research for material Al-Cu band it can be stated, that:

- the optimal value of asymmetry coefficient can be found, for which it will be possible to obtain the uniform distribution of plastic flow velocity of bimetallic band layers on plane on the output from the deformation zone,
- in the range of asymmetry coefficient from 1 to a_{vopt} the gradual straightening out of the band until to getting the straight line plate observed,
- using the higher asymmetry of rotational speed of the roll than a_{vopt} leads to bending the plate in opposite direction,
- the increase of the relative rolling reduction and layer thickness ratio of bimetallic band leads to the necessity of using the higher asymmetry of rotational speed of the rolls to obtain the straight line band on the output from the rolling mill,
- the increase of the hard layer thickness causes higher curvature of bimetallic band on the output of rolling mill,
- the obtained numerical values of asymmetry coefficient are very similar to laboratory values and on the numerical way these values can be easily predicted.

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