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# Numerical modelling of the bimetallic reinforcement bar rolling process

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**Analysis and modelling**

## ABSTRACT

**Purpose:** New kind of reinforcement bars are bimetallic reinforcement bars which has a higher corrosion resistance and mechanical properties, than the standard bars. The bimetallic bars are more and more often applied to building of concrete construction. This kind of application decides about high requirements imposed upon their performance characteristics and mechanical properties.

**Design/methodology/approach:** Using the numerical modelling to rolling process of the bimetallic reinforcement bars in a finished pass to define rolling parameters. The simulations of the ribbed bar rolling were carried out using the Forge2005® commercial program.

**Findings:** It has been performed in order to define the specific features of the mode of metal flow in the roll gap and to determine the effect of the shape and dimensions of the feedstock oval on the height of the ribs and on the thickness of surface layer of the finished bar.

**Practical implications:** Reinforcement bars are chiefly used in the building industry at production of reinforced concrete constructions, and as working elements in bridge building.

**Originality/value:** Production of bimetallic reinforcement bars is very difficult. One from many problems during production bimetallic bars is rolling in the finished passes. In this paper the computer simulation of the rolling bimetallic reinforcement bar is presented.

**Keywords:** Numerical techniques; FEM; Groove-rolling

## 1. Introduction

Bimetallic ribbed bars can be manufactured in medium and small-size shape rolling mills from the previously produced bimetallic feedstock [1-7]. The manufacture of ribbed bars with the outer layer of corrosion-resistant steel is a complicated process and is associated with many technological problems, the most important of which is to obtain a bimetallic feedstock of the proper strength of bond between the core and the cladding layer and to assure the uniform plastic flow of both bimetal layers during the process of rolling in the shape rolling mill in the stretching and forming passes. The main problem in the manufacture of ribbed bars clad with corrosion-resistant steel is to determine the technological conditions of the rolling process. The incorrect design of the scheme of bimetallic band deformation in the stretching and forming passes may be the cause of the effect of the cladding layer "flowing down" from the core surface and the occurrence of a complex state of stress in the finishing pass, which in turn might result in the formation of defects in the cladding layer (such as non-uniform layer thickness, micro-cracks, micro-laminations, etc.). A correctly designed rolling process should assure a uniform cladding layer of an appropriate thickness to be obtained on the bar perimeter and length, which will not break in the finishing pass. During rolling in the finishing pass, the shape and dimension of the preformed bimetallic band are of great importance. The width-to-height ratio of the pre-finished oval pass should be chosen so that the band completely and uniformly fill the rib grooves in the roll during rolling in the finishing pass, with the cladding layer obtaining an equal thickness on the rib surface [5-7].

Table 1.
Dimensions of round ribbed finished pass to rolling of round ribbed bars 16 mm [mm]

| Bimetallic round ribbed bar | D | T | N | Rr | Rz | A | B1 = t | B | β [°] | α [°] | R1 | R2 | R3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Dw =348.38, Dp =341.78 Dr =335.18, Dz =332.98 | 9.9 | 110 | 7.59 | 8.69 | 1.1 | 2.00 | Bs 1.5 Bp 3.7 | 90 | 63.26 | 0.5 | 0.4 | 0.4 |

## 2. Numerical modelling of bimetallic round ribbed bar rolling process

To develop a technology for the manufacture of ribbed bimetallic bars with a corrosion-resistant steel cladding layer, it is necessary to carry out theoretical studies. On the basis of the results of such studies, it will be possible to determine the rolling parameters and to work out the optimal shape of the pre-finished and finishing passes. The rolling parameters obtained from the theoretical studies will enable the shortening of the time and reducing of the costs of experimental tests and technological trials [8-11].

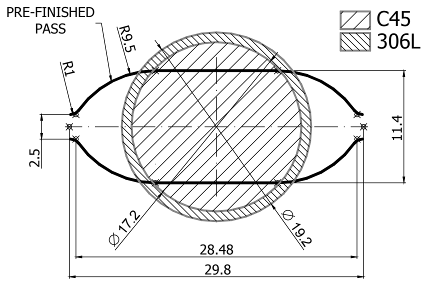


Fig. 1. Shape and dimensions of the pre-finished pass and dimension of initial band

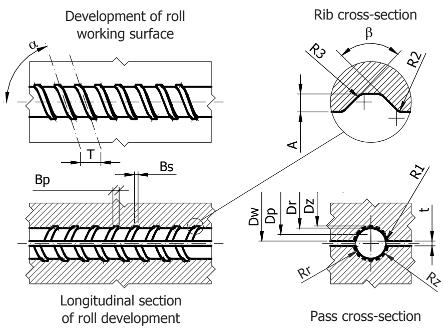


Fig. 2. Shape and dimensions of the round ribbed finished pass

The paper presents the preliminary theoretical studies on the rolling of bimetallic bar in the oval pre-finished pass and the ribbed finished pass. Numerical modelling of the rolling process was carried out in two stages. In the first stage, the rolling of round bimetallic band in the flat oval pre-finished pass was modelled. The shape and dimensions of the oval pre-finished pass are shown in Figure 1. The starting band for rolling in the pre-finished band was 19.2 mm-diameter round bimetallic bar. The outer layer accounted for 20% of the whole cross-sectional area of the bimetallic bar. The core diameter with this outer layer proportion was equal to 17.2 mm. The cladding layer was made of corrosion-resistant steel 306L (according to ASTM). For the bar core, steel C45 was used. In the second stage of studies, numerical modelling of the rolling of oval bimetallic band in the ribbed finished pass was carried out (Fig. 2, Table 1).

### 2.1. Mathematical model of Forge2005® computer program

One of a number of computer programs designed for the modelling of plastic processing processes based on the finite element method is the FORGE2005® commercial software [12,13]. This software offers a possibility to model rolling processes in a three-dimensional strain condition. For a description of the object being deformed, the Norton-Hoff law was used, which can be expressed with the following equation (1):

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

where: $S_{ij}$ - stress tensor deviator, $\dot{\bar{\varepsilon}}$ - strain rate intensity, $\dot{\varepsilon}_{ij}$ - strain rate tensor, $\bar{\varepsilon}$ - strain intensity $\varepsilon_0$ - base strain, $T$ - temperature, material constants $K_0$, $m_0$, $n_0$, $\beta_0$ deal with characteristic properties of a given material.

Friction conditions taking place between the metal and rollers are described by the Coulomb friction model and by the Tresca friction model. The Forge2005® computer program makes it possible to enter steel properties in the form of a function (2):

$$\sigma_p = A_0 \cdot e^{m_1 \cdot T} \cdot \varepsilon^{m_2} \cdot \dot{\varepsilon}^{m_3} \cdot e^{\frac{m_4}{\varepsilon}} \text{ [MPa]}, \tag{2}$$

Table 2.
Coefficients of steels

| Steel | $A_0$ | $m_1$ | $m_2$ | $m_3$ | $m_4$ |
|---|---|---|---|---|---|
| C45 | 1521.3 | -0.00269 | -0.12651 | 0.14542 | -0.05957 |
| 306L | 4321.6 | -0.00305 | 0.10835 | 0.08647 | -0.01270 |

The values of coefficients $A_0$, $m_1$-$m_4$ for both steel were shown in Table 2. The coefficients shown in Table 2 are taken from the material database of the program Forge2005®.

The following initial parameters were adopted for simulation: a roll diameter of 350 mm; the temperature of rolled bimetallic band was assumed to be uniform and equal to 1000°C; the rolling speed was taken equal to 3 m/s, friction coefficient 0.3, and friction factor 0.7.

It was assumed that the joint between the core and the cladding layer was closely adhering. The nodes of both meshes were not shared. The properly chosen size of the mesh on the contact surfaces does not cause any significant problems either during computation or during re-meshing. The thermal conductivity was chosen identical as for the heat exchange between the band and the rolls (20 kW/(K·m$^2$)).

## 3. Numerical modelling results

As a result of the performed computer simulation of the rolling of round bimetallic band in the flat pre-finished pass, an oval band was obtained, as shown in Figure 3.

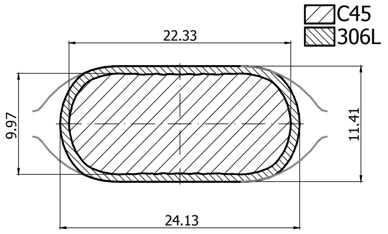


Fig. 3. Shape and dimensions of the bimetallic flat oval band obtained in numerical modelling – cross-section

The dimensions of the oval bimetallic band after rolling in the pre-finished pass were 24.13 x 11.41 mm. The width-to-height ratio of the bimetallic oval amounted to 2.1 [1-6]. The cross-sectional area of the oval bimetallic band was 251.7 mm$^2$, of which the cladding layer area was 49.5 mm$^2$. The initial share of the cladding layer was 19.8% and it did not change after rolling in the oval pass. The elongation factor was equal to 1.13. The initial cladding layer thickness on the perimeter was uniform and equal to 1 mm, whereas after rolling this thickness changed. The thickness of the layer in the locations of band contact with the rolls was 0.72 mm on the average, while on the lateral surfaces in the band widening direction it was equal to 0.9 mm.

On the basis of the obtained theoretical study results, no possibility of formation of surface defects, which could have been caused by high magnitudes of stress and strain, was found. When analyzing the computer simulation results, consideration was given to the Cocroft-Latham criterion that allows the determination of the conditions for the occurrence of a crack in the material based on the main stresses and strain intensities occurring during deformation [14]. The value of this criterion during rolling in the pre-finished pass did not exceed 0.2, which indicates that there are no conditions favouring the cracking of the cladding layer (the criterion value, at which cracks might occur is approx. 0.6, depending on the deformation conditions) [15].

The next stage of the studies was the numerical modelling of the obtained oval bimetallic band in the round ribbed pass (Fig. 2). This pass is used for rolling usual (not bimetallic) ribbed bars. As a result of the studies carried out, the model of the 16 mm-diameter ribbed bimetallic bar was obtained (Fig. 4). Figure 5 shows the dimensions of the cladding layer in the characteristic locations on the ribbed bimetallic bar.

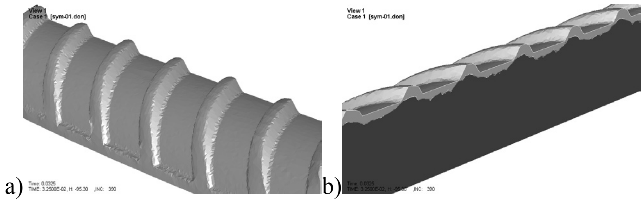


Fig. 4. Bimetallic round ribbed bar model 16 mm: a) view of bar outer layer, b) view of bar longitudinal section

When analyzing the obtained results it can be found that the obtained bimetallic ribbed bar model is characterized by correct outer dimensions and a correct rib height of 1.1 mm. The bar width was equal to 16.4 mm and was within the negative dimensional tolerance. The thickness of the cladding layer between the ribs was equal to 0.61 mm on the average, with a deviation of ±0.07 mm. At the rib top, this layer reached the thickness ranging from 0.9 mm to 1.0 mm. On the cross-section A and B (Fig. 5) it is shown how the cladding layer thickness varies on the core surface. A smaller cladding layer thickness can be observed at the rib base, for both the cross-section and the longitudinal section. The thickness of this layer in these places depends on the rolling direction. At the rib base on the side opposite to the rolling direction, the cladding layer thickness is averagely 0.55 mm. On the other side of the rib, this thickness is much smaller, amounting to 0.22 mm on the average.

The cause of such a large difference in cladding layer thickness is the mode of rib formation in the rolls bite region. Figure 6 show the formation of ribs in the initial zone of the rolls bite region. The cause of such a large difference in cladding layer thickness is the mode of rib formation in the rolls bite region. Figure 6 show the formation of ribs in the initial zone of the rolls bite region.

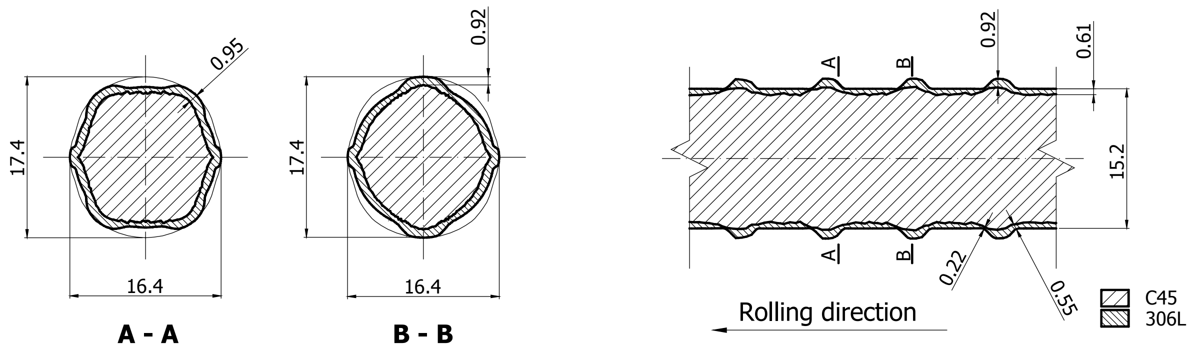


Fig. 5. Shape and dimensions bimetallic round ribbed bar 16 mm obtained in computer simulation

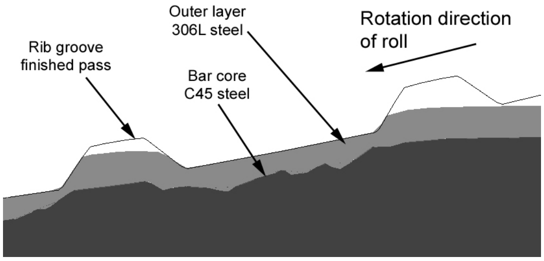


Fig.6. Forming of bimetallic bar ribs in ribbed finished pass

During rolling the oval bimetallic bar in the ribbed finished pass, ribs are formed as a result of filling of the pass grooves. Due to the fact that the plastic resistance of the core is high and a free space occurs in the pass groove, the metal (cladding layer) displaces in this particular direction to cause a reduction in cladding layer thickness at the rib base. In addition, a factor influencing the reduction of the cladding layer thickness is the lag phenomenon occurring at the beginning of the rolls bite region. This results in the occurrence of a difference in speed between the roll surface and the bar surface, which creates unfavourable conditions for the formation of a rib and decreases the cladding layer thickness. In the central part of the roll bite region those speeds equalize and filling of the rib groove follows. At exit from the rolls bite region, the speed of the cladding layer is higher than that of the rolls. The interaction of the rib grooves in this location increases the rib height and the complete filling of the rib grooves. The conditions prevailing in this part of the rolls bite region do not have any effect on increasing the height of the cladding layer at the rib base.

## 4. Conclusions

The theoretical studies carried out have proved that the computer program Forge2005® makes it possible to carry out the numerical modelling of the rolling of ribbed bimetal bars and to make the analysis of this process.

From the study results, a substantial reduction in cladding layer thickness at the rib base has been found, which is asymmetrical in relation to the rib axis and is dependent on the rolling direction.

Further studies will enable the determination of the rolling parameters that allow obtaining a bimetallic ribbed bar of the thinnest possible corrosion-resistant layer without cracks in it.

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