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Numerical analysis of the 45 mm reinforcement bar rolling process

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Analysis and modelling

ABSTRACT

Purpose: The paper presents the results of theoretical investigations of the process of rolling reinforcement bars designed for concrete reinforcement. In the investigation. particular consideration was given to the analysis of the effect of pre-finished band shape on the formation of ribs on the finished bar in the finished pass.

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

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.

Research limitations/implications: The use of commercial software applications in the design of process technologies will allow for the development of reinforcement bars rolling technology with a minimum number of laboratory and industrial trials.

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 the reinforcement bars is very difficult. One from many problems during production the bars is rolling in the finished pass. In this paper the computer simulation of the rolling reinforcement bar is presented.

Keywords: Numerical techniques; FEM; Groove-rolling

1. Introduction

Concrete reinforcement bars are chiefly used in the building industry at production of reinforced concrete constructions. and as working elements in bridge building. This kind of application decides about high requirements imposed upon their performance characteristics and mechanical properties. Reinforced bars buyers demand them to have a high durability, ductility, corrosion resistance, good weldability, and high fatigue strength. An important factor, which provides for the common bearing of a bar and concrete, is their mutual adhesion that is highly dependent upon dimensions and positioning of ribs at the bars surface, i.e. upon its ribs structure [1-4].

While designing new reinforced bars constructions, one of the chief objectives is to achieve a high level of their performance characteristics. This is attained through lowering a concentration of strains in finished bars and raising their mechanical properties, including fatigue strength. Another objective is to obtain a high-precision geometry of a bar in terms both of its shape and dimensions.

Concrete reinforcement bars 45 mm may by produce on the medium size shape rolling mills where smooth bars are made in the range of diameters from 6 mm to 60 mm [5-7].

The essence of a concrete reinforcement bar rolling process is the occurrence in it of a unique pre-finished oval pass and a finished pass with rib undercut at roller circumference.

Within the frameworks of this work, a theoretical analysis was carried out of the rolling process of 45 mm reinforcement bar in pre-finished and finished passes.

Numeric calculations were performed of the metal flow process in these passes with the use of the Forge2005® software. The research program included defining the influence made by a pre-finished band cross sectional shape upon the shape and dimensions of the bar and its ribs.

2. Numerical modelling of the reinforcement bar rolling process

The purpose of the investigation was to determine the preparatory band shape and the pre-finished pass shape that would enable the production of a 45 mm-diameter ribbed bar of the correct core dimensions and the appropriate rib height.

The problem encountered during the rolling of ribbed bars of a diameter above 25 mm is to obtain the proper height and shape of ribs [1,5,6]. In a bi-skew ribbed bar, the filling of the roll grooves is more difficult to achieve due to the different rib skewing angles. Finished pass rib grooves of a smaller inclination angle are more difficult to fill with metal. The shape of ribs on finished bar is dependent on the preformed band shape that must be properly selected. Figure 1 shows a 45 mm-diameter ribbed bar, while the bar dimensions are given in Table 1.

2.1. Scheme of research

The examination was conducted for two variants: in the first variant, rolling was conducted following the guidelines applicable to industrial conditions (the roll gap in the preparatory pass was 8 mm), whereas in the second variant a modification was made, which involved change to the preformed band shape by increasing the roll gap from 8 mm to 12.5 mm. Figure 2 illustrates schematically both variants of numerical modelling.

For carrying out simulation, roll models were developed according to the passes shown in Figures 3 and 4.

The analysis of the process of rolling 45 mm ribbed bar was made by numerical modelling carried out using the Forge2005® program based on the finite-element method. This program is designed for the modelling of plastic working processes [8,9]. 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 [10-13].

2.2. Mathematical model of Forge 2005®

One of a number of computer programs designed for the modelling of plastic processing processes based on the finite element method is the Forge 2005® commercial software [14]. 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 [14,15]:

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

where: S_{ij} - Stress tensor deviator, $\dot{\bar{\varepsilon}}$ - strain rate intensity, $\dot{\varepsilon}_{ij}$ - strain rate tensor, $\bar{\varepsilon}$ - strain intensity, ε_0 - base strain, T - temperature, material constants, K_0, m_0, n_0, β_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. in which appropriate values of coefficients are assumed [14]:

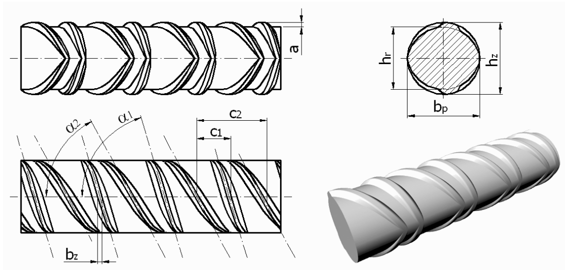

Fig. 1. Shape and dimensions of the reinforcement bar 45 mm

Table 1.
Dimensions of the reinforcement bar 45 mm

Diameter	Core height	Bar height	Bar weigh	Rib width	Rib width	Rib pitch		Rib angle	
d	h_r	h_z	b_p	b_z	a	c_1	c_2	α_1	α_2
45	40.7	47	46.9	4.5	3.15	21.0	42.0	55	71

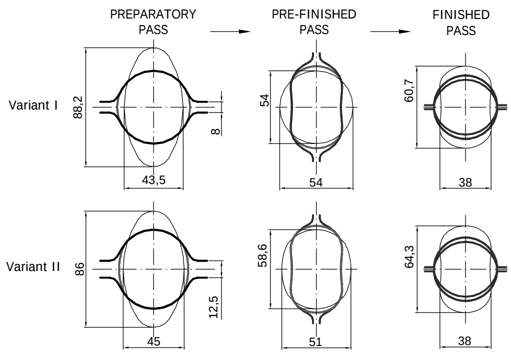

Fig. 2. Scheme of the 45 mm reinforcement bar rolling process

a) b)

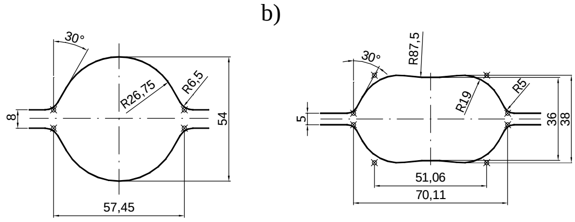

Fig. 3. Pre-finished pass: a) round pass, b) oval pass

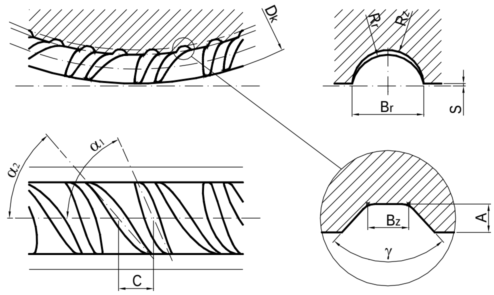

Fig. 4. Finished pass to rolling of the reinforcement bar

Table 2
Dimension of ribbed finished pass

D_k	C	A	B_z	B_r	R_r	R_z	S	α_1	α_2	γ
450	22.0	3.15	4.5	46.9	24.0	23.5	3.0	72.1	57.1	85

$$\tau_j = \mu \cdot \sigma_n \quad \text{for} \quad \mu \cdot \sigma_n < \frac{\sigma_0}{\sqrt{3}}. \tag{2}$$

$$\tau_j = m\frac{\sigma_0}{\sqrt{3}} \quad \text{for} \quad \mu \cdot \sigma_n > m\frac{\sigma_0}{\sqrt{3}} \tag{3}$$

where: τ_j – friction stress, σ_0 – base stress, σ_n –normal stress, μ - friction coefficient, m – friction factor.

2.3. Plastometric test of the BSt500S steel

The accuracy of calculations performed by means of the Forge 2005® computer software, using the finite element method, is dependent upon an exact identification of properties of materials used within the research [9].

Experimental tests for BSt500S steel (of which square ribbed wire rods are made) were conducted at the Czestochowa University of Technology Institute of Modelling and Automation of Plastic Working Processes. Material properties were defined upon the basis of plastometric tests carried out with the use of the physical simulator Gleeble 3800.

2.4. Initial parameters

The following initial parameters were adopted for simulation: a roll diameter of 450 mm; the temperature of rolled band was assumed to be uniform and equal to 1000°C; the rolling speed was taken equal to 7 m/s, friction coefficient 0.3 and friction factor 0.7. The thermal conductivity between the band and the rolls was 10 kW/(K·m^2) and air conductivity was 10 W/(K·m^2).

3. Results of the numerical modelling

As a result of the performed numerical examination of the rolling process in two variants, the models of preparatory and preformed bands, and the models of finished ribbed bars were obtained. Figure 5 shows the shape of bands obtained after successive passes. Table 3 compares the dimensions and elongation factors for the successive passes of rolling in two variants.

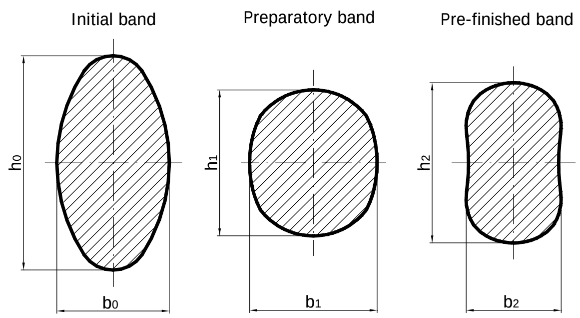

Fig. 5. Shape and dimensions bands in the numerical modeling of rolling process was obtained

Figure 6a shows a sample model of ribbed bar obtained from computer simulation, whereas Figure 6b gives the specific dimensions of the 45 mm-diameter ribbed bar. Bar dimensions for both variants are shown in Table 4.

Table 3
Rolling parameters for the following passes.

Variant	Feed stock			Preparatory band				Pre-finished band				Finished band			
	Width b_0 [mm]	Height h_0 [mm]	Area A_0 [mm^2]	Width b_1 [mm]	Height h_1 [mm]	Area A_1 [mm^2]	Elongation λ_1	Width b_2 [mm]	Height h_2 [mm]	Area A_2 [mm^2]	Elongation λ_2	Width b_p [mm]	Height h_z [mm]	Area A_p [mm^2]	Elongation λ_3
I	43.5	88.2	2973	54.0	54.0	2290	1.298	38.0	60.7	2021	1.133	44.3	46.7	1567	1.290
II	45.0	86.0	2999	58.6	51.0	2436	1.231	38.0	64.3	2144	1.136	46.1	47.0	1585	1.353

Table 4
Dimensions of the reinforcement bars 45 mm for two variants, [mm]

Variant	Bar width		Bar Height (with ribs)		Bar height (core)		Ribs height (ave.)		Rib pitch (predefined 21.00)
	b_{pA}	b_{pB}	h_{zA}	h_{zB}	h_{rA}	h_{rB}	a_A	a_B	$(c_1 + c_2)/2$
I	44.3	44.3	46.9	46.4	40.7	40.7	3.10	2.65	22.46
II	46.1	46.2	47.0	47.0	40.7	40.7	3.15	3.15	22.61

a) b)

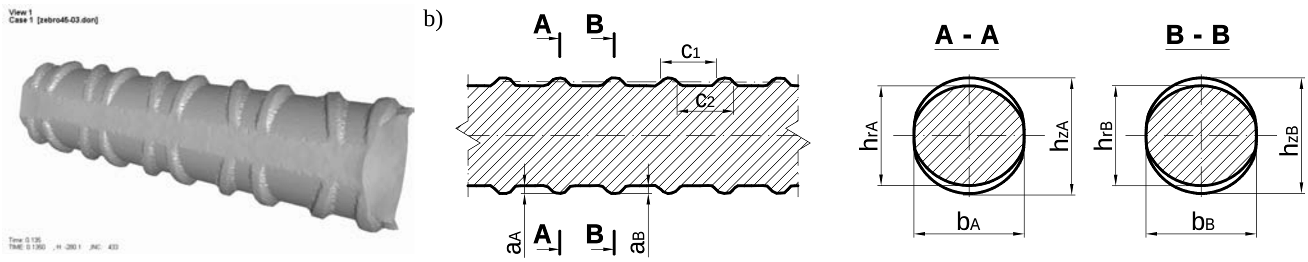

Fig. 6. Reinforcement bar 45 mm: a) model obtained in numerical modeling, b) shape and dimensions of model

When analyzing the results obtained from the numerical examination it can be noted that no overfilling occurred in any pass. In rolling of the pre-oval band in the pre-finished oval pass, two oval bands with a radial undercut were obtained, which were characterized by the b/h ratio equal to 1.60 for Variant I and 1.70 for Variant II. The shape of the pre-formed oval obtained in Variant I does not assure a finished bar of the proper rib height to be obtained. The rib grooves have not been filled completely. The rib height in the A-A cross-section (ribs of an inclination angle of α_1=72°) amounted to 3.1 mm on average, while the ribs in the B-B cross-section (ribs of an inclination angle of α_2=57°) were lower, amounting to 2.7 mm. The cause of the difference in rib height are the conditions of metal flow in the roll gap. During rolling, the distributions of the components of metal flow velocities in the rib regions are different. For larger inclination-angle ribs, the component of flow velocity is higher in the height direction, and lower in the widening direction. For smaller inclination-angle ribs, the component of flow velocity in the height direction is lower, which results in a smaller rib height. The higher flow velocity in the widening direction causes larger bar width in locations, where the smaller inclination-angle rib occurs (Table 4, Variant II, dimension b_{pB}). Part of the metal volume flows in the width direction. Although the variations in bar width are small, this still has a substantial influence on the rib height.

Increasing the pre-formed band height (h_2/b_2=1.7) by roll gap modification and increasing the cross-sectional area of the initial band resulted in a greater rolling reduction in the finishing ribbed pass. This contributed to the obtaining of an equal height of ribs inclined at an angle of 72° and 57°, respectively.

Increasing the dimensions of the initial band (Variant II) caused an increase in elongation factors in the pre-finished and finished passes, and a decrease in the preparatory pass. This influenced the rib pitch, which elongated by 0.15 mm compared to Variant I. The difference in rib pitch length for this type of rib shape is not so much significant. The elongation of the rib pitch for both variants compared to the pitch length designed on the rolls is, however, important. According to the standard applicable to ribbed bars, the dimension of the rib pitch shall not be greater than 21.0 mm. On the finished bar, the ribs pitch of equal to 22.54 mm were obtained. The value was greater than 21.0 mm and it wasn't performing the standard.

4. Conclusions

- During rolling of bi-skew ribbed bars, the deformation in the finished ribbed pass should be increased; this will assure an equal rib height to be obtained.
- When designing rolls and a finished pass for rolling ribbed bars, the pitch elongation, should be accounted for.

References

[1] V. Danchenko, H. Dyja, L. Lesik, L. Mashkin, A. Milenin, Technology and modelling of rolling processes in grooves, Częstochowa, (in Polish), (2002).
[2] A. Abdullah, Almsallam, Effect of degree of corrosion on the properties of reinforcing steel bars, Elsevier, Constructions and Building Materials 15 (2001) 361-368.
[3] M. Maslehuddin, M.M. Al-Zahrani, S.U. Al-Dulaijan, Abdulquddus, S. Rehman, S.N. Ahsan, Effect of steel manufacturing process and atmospheric corrosion on the corrosion-resistance of steel bars in concrete, Cement and Concrete Composites 24 (2002) 151-158.
[4] H. Dyja , P. Szota , S. Mróz, 3D FEM modelling and its experimental verification of the rolling of reinforcement rod, Journal of Materials Processing Technology 153-154 (2004) 115-121.
[5] P. Szota, H. Dyja, Numerical modelling of the metal flow during the rolling process of the round screw-ribbed bar in the finishing pass, Journal of Materials Processing Technology 177 (2006) 566-569.
[6] P. Szota, S. Mroz, H. Dyja, The numerical modeling of the rolling round reinforcement rod and influence of the oval pre-finished dimensions on the height of the ribs, conference AISTech 2005 2 (2005) 573-584.
[7] F. Capece Minutolo, M. Durante, F. Lambiase, A. Langella, Dimensional analysis of a new type of groove for steel rebar rolling, Journal of Materials Processing Technology 175 (2006) 69-76.
[8] S. Mróz., K. Jagieła., H. Dyja, Determination of the energy and power parameters during groove-rolling, Journal of Achievements in Materials and Manufacturing Engineering 22/2 (2007) 59-62.
[9] A. Kawałek, The analysis of the asymmetric plate rolling process, Journal of Achievements in Materials and Manufacturing Engineering 23/2 (2007) 63-66.
[10] T. Da Sisva Botelho, E. Bayraktar, G. Inglebert, Comparison of experimental and simulation results of 2D-draw-bend springback, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 275-278.
[11] P. Šimeček, D. Hajduk, Prediction of mechanical properties of hot rolled steel products, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 395-398.
[12] I.H. Son, Y.G. Jin, Y.T. Im, Finite element investigations of friction condition in equal channel angular extrusion, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 285-288.
[13] I.S. Kim, J.S. Son, H.J. Kim, B.A. Chin, A study on variation of shielding gas in GTA welding using finite element method, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 249-252.
[14] FORGE3® Reference Guide Release 6.2, Sophia-Antipolis, (2002).
[15] O.C. Zienkiewicz, R.L. Taylor, Finite Element Method, 5th Edition, Butterwortth–Heinemann, Woburn, (2000).