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The effect of degree of deformation on forward slip in experimental research on cold longitudinal rolling of flat bars made from EN AW-6063 aluminium alloy

Wpływ stopnia odkształcenia na wyprzedzenie w badaniach doświadczalnych walcowania wzdłużnego na zimno płaskowników ze stopu aluminium EN AW-6063

Abstract

The paper presents experimental results that concern cold longitudinal rolling of flat bars made from EN AW-6063 aluminium alloy. The investigations aimed at determining the impact of the degree of deformation of material on the forward slip. The forward slips were calculated from Fink's, Drezden's and Vinogradov's formulae. On the basis of investigations of the cold longitudinal rolling of flat bars made from aluminium EN AW-6063, it was found that the forward slip increases with an increase in degree of deformation of material.

Keywords: longitudinal rolling, forward slip, EN AW-6063

Streszczenie

W artykule przedstawiono wyniki badań doświadczalnych walcowania wzdłużnego płaskowników na zimno ze stopu aluminium EN AW-6063. Ich celem było określenie wpływu stopnia odkształcenia na wyprzedzenie materiału. Wielkość wyprzedzenia była obliczana ze wzorów Finka, Drezdena i Vinogradova. Na podstawie przeprowadzonych badań stwierdzono m.in., że wyprzedzenie wzrasta wraz ze wzrostem stopnia odkształcenia materiału.

Słowa kluczowe: walcowanie wzdłużne, wyprzedzenie, EN AW-6063

1. Introduction

The rolling process belongs to compressive deformation processes and has been classified on the basis of kinematics, tool and workpiece geometry. Based on kinematics, the rolling process can be classified as longitudinal, cross and skewed [1–3]. In longitudinal rolling (Fig. 1), the workpiece moves through the rolling gap perpendicular to the axis of the rolls, without rotation about the workpiece axis [1–3]. In the exit zone of deformation, the horizontal component of the roll circumferential velocity is less than the workpiece velocity. This phenomenon is called the forward slip [1].

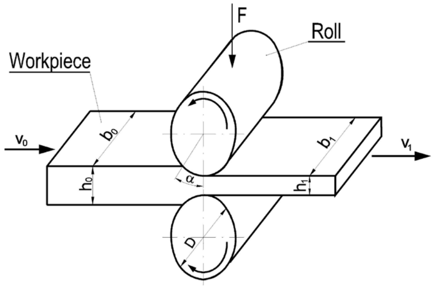

Fig. 1. Nomenclature in flat longitudinal rolling

Values of the forward slip were calculated from Fink's, Drezden's and Vinogradov's formulae [1, 4]. The forward slip is given by the equation of Fink below (1) [1,4]:

$$S_w = \frac{\left[h_1 + D(1-\cos\gamma)\right]\cos\gamma}{h_1} - 1 \tag{1}$$

where:

h_1 – height of the material after deformation (mm),
D – the diameter of a mill roll (mm),
γ – parting plane angle is given by Ekelund formula (2) [4]:

$$\gamma = \sqrt{\frac{\Delta h}{2D}} - \frac{\Delta h}{2D\rho} \tag{2}$$

where:

ρ – the friction angle can be determined by the following formula (3) [4]:

$$\cos\rho = \frac{1}{\sqrt{1+\mu^2}} \tag{3}$$

where:

μ – the friction coefficient is (4) [4]:

$$\mu = \sqrt{\frac{1}{\left(1 - \frac{\Delta h_{\max}}{D}\right)} - 1} \tag{4}$$

where:

Δh_{max} – the high reduction for maximum deformation.

The following formula can be used to obtain the forward slip of Drezden theory (5) [1, 4]:

$$S_w = \frac{R}{h_1}\gamma^2 \tag{5}$$

The forward slip may be estimated from Vinogradov's formula given below (6) [1, 4]:

$$S_w = \frac{\left[b_0 + \Delta b\left(1 - \frac{\gamma}{\alpha_{ch}}\right)\right]\left[h_1 + D(1-\cos\gamma)\right]\cos\gamma}{(b_0 + \Delta b)h_1} \tag{6}$$

where:

b_0 – width oft he material before deformation (mm),

Δb – spreading of the material (mm),

α_{ch} – roll bit angle can be determined by (7) [4]:

$$\alpha_{ch} = \arccos\left(1 - \frac{\Delta h}{D}\right) \tag{7}$$

The degree of deformation of materials for rolling are defined in literature [1–4]. They are given in Table 1.

Table 1. Degrees of deformation of material after rolling [4]

Relationship is valid for:	height reduction	spreading	elongation
	of flat bar		
Geometrical relationship, mm	$\Delta h = h_0 - h_1$	$\Delta b = b_1 - b_0$	$\Delta l = l_1 - l_0$
Relative strain	$\varepsilon_{wh} = \frac{\Delta h}{h_0}$	$\varepsilon_{wb} = \frac{\Delta b}{b_0}$	$\varepsilon_{wl} = \frac{\Delta l}{l_0}$
Percent deformation, %	$G_h = 100\,\varepsilon_{wh}$	$G_b = 100\,\varepsilon_{wb}$	$G_l = 100\,\varepsilon_{wl}$
Ratio of strain	$\gamma = \frac{h_1}{h_0}$	$\beta = \frac{b_1}{b_0}$	$\lambda = \frac{l_1}{l_0}$
Logarithmic strain	$\varepsilon_h = \ln\gamma$	$\varepsilon_b = \ln\beta$	$\varepsilon_l = \ln\lambda$

Cold longitudinal rolling process of flat bars and the design of the tooling have been reported in some studies [5–8].

The paper presents experimental results that concern cold longitudinal rolling of flat bars made from aluminium EN AW-6063. The investigations aimed at determining the impact of the degree of deformation of material on the forward slip. The friction factor was determined by formula (4) and forward slips were calculated by means of Fink's, Drezden's and Vinogradov's formulae (1), (5), (6). The degrees of deformation of material in investigations were defined as relative strain ε_w and logarithmic strain ε (formulae are given in Table 1). EN AW-6063 alloy aluminium was selected as the testing material in these investigations due to its good formability and wide applications in industry [9, 10].

2. Methodology

Samples made from aluminium EN AW-6063 constituted the material for experimental investigations into cold longitudinal rolling process. Chemical composition of material [11] is shown in Table 2.

Table 2. Chemical composition of EN AW-6063 alloy aluminium [%] [11]

Mg	Si	Fe	Ti	Zn	Cr	Mn	Cu	Unspecified other elements		Al minimum
								Each	Total	
0.45–0.9	0.20–0.6	max. 0.35	max. 0.10	max. 0.10	max. 0.10	max. 0.10	max. 0.10	max. 0.05	max. 0.15	rem

Mechanical properties of the material were determined by static tensile testing (R_m = 260 MPa, $A_{11.3}$ = 13,8 % , Z = 11.2%). The tensile test was conducted on *LabTest5.20SP1* testing machine (*LABORTECH* firm) with 20 kN force. The machine was calibrated by PN-EN ISO 7500-1:2005 and meets the metrological requirements for class 0.5.

The samples used in experimental investigations into cold longitudinal rolling were made of segments of flat bars with the height of h_0 = 5 mm, width of b_0 = 20 mm and length of l_0 = 40 mm. The longitudinal rolling process is conducted at a special stand – rolling mill DUO-100. The rolling mill has two mill rolls at diameter D which equals 102 mm [12].

The samples were rolled by using extraction naphtha as lubricant. Extraction naphtha is a complex mixture of hydrocarbons obtained by treatment of petroleum fraction with hydrogen in the presence of a catalyst. It consists of hydrocarbons with a number of carbon atoms ranging from C_4 to C_{11}, where the range of boiling point is from –20°C to 190°C. It is used as a solvent in the paint and varnish industry as well as in metal and rubber industry. Extraction naphtha is applied to the production of adhesives. It is used to cleaning and degreasing in dry cleaners and tanneries as well as in service workshops. Extraction naphtha is a colorless liquid with a flash point below 0°C. Its density at 15°C ranges from 0,62 to 0,88 g/cm^3. It can be dissolved in most organic solvents, hydrocarbons, alcohols, ethers, carbon disulphide, carbon tetrachloride and chloroform [13].

3. Results and analysis

The friction factor was determined by the method of the roll bite angle. This method involves rolling samples at maximum degree of deformation. On the basis of geometric parameters of samples after deformation measurements, the value of the roll bite angle (α_{ch} = 15.58°) friction factor (μ = 0.28) and forward slips were calculated from formulae (1)÷(7). The deformation ratios of material in paper were defined as relative strain ε and logarithmic strain ε: on the high ε_{wh}, ε_h; on the width ε_{wb}, ε_b and on the length ε_{wl}, ε_l, respectively. The nomenclature in table formulae is shown in Fig. 1. For the calculation of the forward slip formulae, the following have been considered: Fink (1), Drezden (5) and Vinogradov (6). Of these formulae, those of Fink and Drezden do not take into account spreading of material Db and its influence on the forward slip. However, in all these formulae the parting plane angle γ is calculated neglecting the influence of spreading.

The influence of relative strain and logarithmic strain on the forward slip in cold longitudinal flat rolling for specimens made from aluminium EN AW-6063 is shown in diagrams (in Fig. 2 and Fig. 3, respectively).

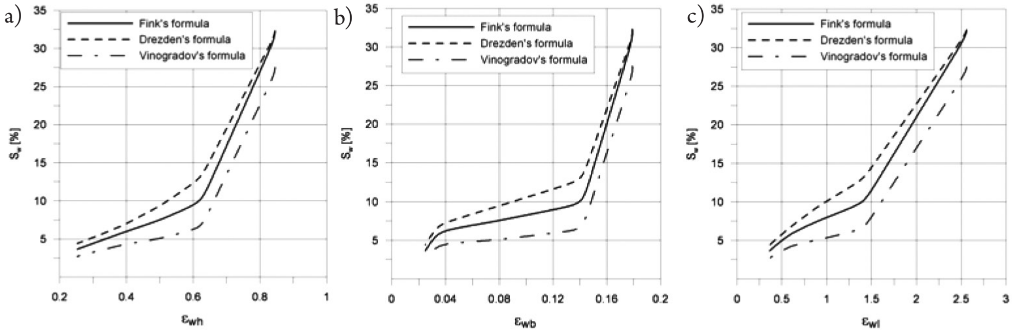

Fig. 2. Influence of relative strain on the forward slip in cold longitudinal flat rolling for specimens made from EN AW-6063 alloy aluminium (extraction naphtha as a lubricant of rolls): a) strain calculated on height ε_{wh}, b) strain calculated on width ε_{wb}, c) strain calculated on length ε_{wl}

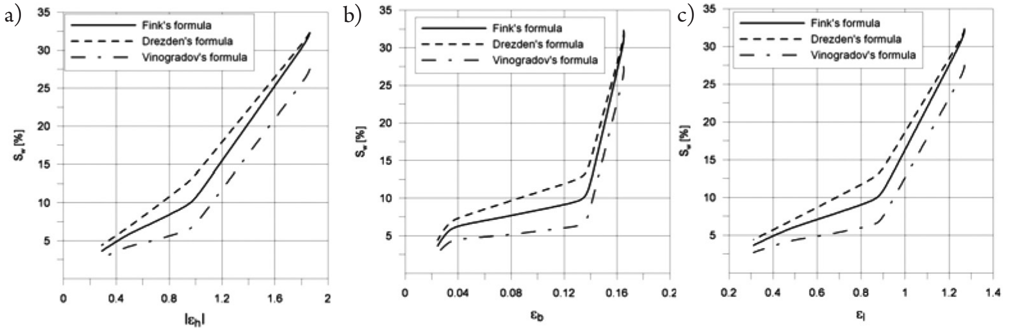

Fig. 3. Effect of logarithmic strain on the forward slip in cold longitudinal flat rolling for specimens made from EN AW-6063 alloy aluminium (extraction naphtha as a lubricant of rolls): a) strain calculated on height ε_h, b) strain calculated on width ε_b, c) strain calculated on length ε_l

The values of logarithmic strain on the high ε_h were less than zero and therefore they were assumed as algebraic modules in the graph (Fig. 3a). Calculated forward slips increase with an increase in relative and logarithmic strain (extraction naphtha as lubricant).

4. Summary

On the basis of investigations carried out into cold longitudinal rolling of flat bars made from aluminium EN AW-6063 (extraction naphtha as a lubricant of rolls), it can be stated as follows:

1. Calculated forward slips S_w in all cases (Fink's, Drezden's and Vinogradov's formulae) increase with an increase in relative and logarithmic strain.
2. Values of forward slips calculated by means of Fink's, Drezden's and Vinogradov's formulae (1), (5), (6) did not differ much at the same friction factor $\mu = 0.28$ and in all cases considered they were the greatest for Drezden's formula (5), whereas the lowest values were obtained for Vinogradov's formula (6).
3. Fink's (1), Drezden's (5) and Vinogradov's (6) formulae, used for calculating the forward slip in longitudinal rolling can be applied in engineering practice. Its knowledge is necessary to determine the workpiece velocity in the exit zone of deformation.

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