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The Influence of Friction Coefficient on Forward Slip in Experimental Research on Cold Longitudinal Flat Rolling

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Abstract. The paper presents experimental results that concern cold longitudinal rolling of flat bars made from EN AW-6063 aluminium for different conditions. The investigations aimed at determining the impact of friction factors on the forward slip. The friction factors were determined by the method of the roll bite angle. The forward slips were calculated from Fink's, Drezden's and Vinogradov's formulae. On the basis of investigations of cold longitudinal rolling of flat bars made from EN AW-6063 aluminium, it was found that the forward slip increases with an increase in friction factor.

Introduction

Rolling is the most extensively used metal forming process and it accounts for almost 90% of metal produced by forming. In this process, the material to be rolled is drawn by means of friction into the gap between two revolving rolls. Compressive forces applied by the rolls reduce the thickness of the material or change its cross-sectional area. The rolling process belongs to the 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 [1-2].

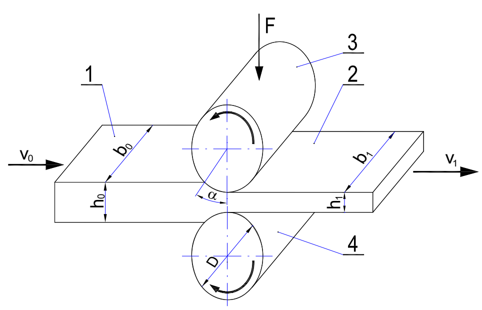

Fig.1 Nomenclature in plate rolling, where: 1 – material before deformation, 2 – material after deformation, 3,4 – mill rolls

In addition to conventional methods of rolling, there are also special methods, as the WPM method, for example. The most essential features of this method, which distinguish it from other known methods, involve the use of two circular segments as the tools and the adoption of kinematics that allows one-directional rolling with a symmetrical system of forces relative to the axis of the rolled material. The WPM method of cold rolling allowed cylindrical gears, involute splines and other circular profiles to be formed [3].

As can be seen from Fig. 1, in longitudinal rolling, the workpiece moves through the rolling gap perpendicular to the axis of the rolls, without rotation about the workpiece axis [1-2]. In the exit zone of deformation, the horizontal component of the roll circumferential velocity is less than the workpiece velocity. This phenomenon is called a forward slip [1]. The values of a 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]:

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

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

$$\gamma = \sqrt{\frac{\Delta h}{2D}} - \frac{\Delta h}{2D\rho} \quad (2)$$

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

$$\cos\rho = \frac{1}{\sqrt{1+\mu^2}} \quad (3)$$

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

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

where:Δh_{max} - the high reduction for maximum deformation.
The following formula can be used to obtain the forward slip of the Drezden theory (5) [1,4] :

$$S_w = \frac{R}{h_1}\gamma^2 \quad (5)$$

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

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

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]:

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

Cold longitudinal rolling process of flat bars and the design of the tooling have been reported in some studies [5-11]. Those covered both experimental and computer modeling investigations.

The paper presents experimental results that concern cold longitudinal rolling of flat bars made from EN AW-6063 aluminium for different conditions. The investigations aimed at determining the impact of friction factors 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).

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EN AW-6063 aluminium was selected as the testing material in these investigations due to its good formability and wide applications in industry [12-13].

Materials

Samples made from EN AW-6063 aluminium constituted the material for experimental investigations into cold longitudinal rolling process. Chemical composition of material [12] is shown in Table 1. The mechanical properties of the material, determined by static tensile testing, are presented in Table 2.

Table 1 Chemical composition of EN AW-6063 aluminium [%] [12]

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

Table 2 Mechanical properties of specimens made from EN AW-6063 aluminium

R_m, [MPa]	$A_{11.3}$, [%]	Z, [%]
260	13.8	11.2

The tensile test was conducted on a LabTest5.20SP1 testing machine (LABORTECH firm) with the force of 20 kN. The machine was calibrated by PN-EN ISO 7500-1:2005 and meets metrological requirements for class 0.5. The mechanical properties indicate a strain hardening of the material after cold work. Flow curve of the sample made from from EN AW-6063 aluminium is presented in Fig. 2.

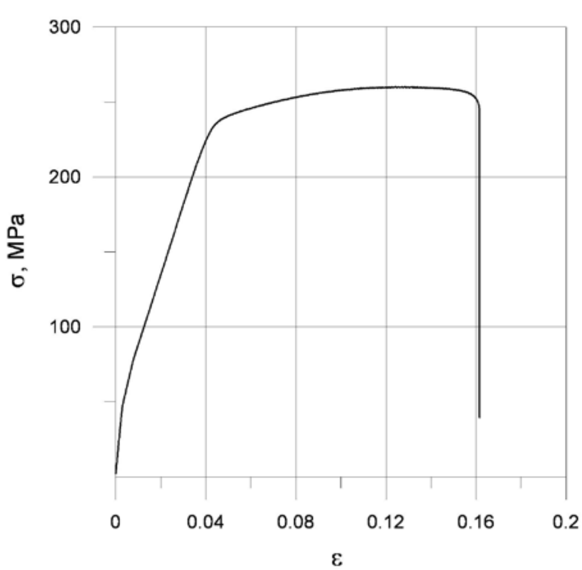

Fig. 2 The flow curve for EN AW-6063 aluminium

The samples used in experimental investigations into cold longitudinal rolling were made of segments of flat bars with the high 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 – a DUO-100 rolling mill. The rolling mill has two mill rolls at diameter D equals 102 mm. The samples were rolled in different conditions. Commonly used lubricants, such as extraction naphtha, kerosene and mineral oil were chosen for the experiment [14]. In addition, motor and rapeseed oils were used.

Extraction naphtha is a complex mixture of hydrocarbons obtained by the treatment of petroleum fraction with hydrogen in the presence of a catalyst. It consists of of hydrocarbons with number of carbon atoms in the range from C_4 to C_{11} whose boiling point ranges from 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 production of adhesives. It is used for cleaning and degreasing in dry cleaners and tanneries as well as in service workshop. Extraction naphtha is a colourless liquid with a flash point below 0 °C. Ist density at 15 ^{0}C ranges from 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 [15].

Kerosene is a complex mixture of hydrocarbons obtained during the process of removing acidic substances. It consists of hydrocarbons with a number of carbon atoms in the range from C_9 to C_{16}. The boiling point of kerosene is from approx. 150 ^{o}C to 290 ^{o}C. Kerosene is a cleaner used to clean metal machine parts, especially rolling bearings (to remove lubricants). It has anti-corrosive properties. Its flash point is above 61 ^{0}C and density at 15 ^{0}C ranges from from 0,75 to 0,86 g/cm^3 [15].

The LHL-46 mineral oil (Hydrol LHL-46) is a mixture of basic mineral oils and refining additives. It is applied in low and medium-loaded systems of force transmission as well as hydraulic drive and control. Its relative density is approx. 0.85÷0.90 g/cm^3. The minimum of flash point equals 190 ^{0}C and maximum flow temperature equals -12 ^{0}C. The LHL-46 oil dissolves in hydrocarbons but is not soluble in water [14,16].

The evolution 700STI 10W40 motor oil (brand of the ELF) is a semi-synthetic oil which is a combination of base synthetic and mineral oils as well as anti-wear additives. It is recomended for all gasoline and diesel engines in cars. Its density at 15^{0}C equals 863 kg/m^3 and flash point equals 232 ^{0}C. The oil is insoluble in water and ist viscosity at 40 ^{0}C equals 96.81 mm^2/s [17].

The rapeseed oil is a deeply refined oil with high oxidative stability. It is applied in the food industry or as a raw material for carrying out chemical changes. The rapeseed oil is used as diesel fuel, either as biodiesel, straight in heated fuel systems, or blended with petroleum distillates for power motor vehicles. Its density at 20^{0}C equals 0.92 g/cm^3 and viscosity at 40 ^{0}C equals 35.40 mm^2/s [18].

Experimental results

The friction factors were determined by the method of the roll bite angle. This method involves rolling samples at the maximum degree of deformation. On the basis of geometric parameters of samples after deformation measurements, the values of roll bite angles, friction factors and forward slips were calculated from formulae (1)÷(7).

The deformation ratios of material in paper were defined as relative strain ε: on the high ε_{wh}, on the width ε_{wb}, the length ε_{wl}, respectively. The maximum values of deformation for different conditions of cold longitudial rolling are presented in Table 3. Nomenclature in table formulae is shown in Fig. 1.

Table 3. The maximum values of relative strain for samples made from EN AW-6063 aluminium for different conditions of cold longitudinal rolling

Relative strain	Lubrication:				
	extraction naphtha	kerosene	mineral oil	motor oil	rape oil
$\varepsilon_{wh} = \frac{\Delta h}{h_0}$	0.75	0.81	0.45	0.51	0.62
$\varepsilon_{wb} = \frac{\Delta b}{b_0}$	0.16	0.33	0.06	0.09	0.15
$\varepsilon_{wl} = \frac{\Delta l}{l_0}$	2.54	3.60	0.71	0.86	1.39

For comparison, values of roll bite angles, friction factors and forward slips are shown in Table 4. For calculation of the forward slip formulae, the following have been considered: Fink, Drezden and Vinogradov. Of these formulae, those of Fink and Drezden do not take into account spreading of Δb material and its influence on the forward slip. However, in all these formulae the γ parting plane angle is calculated neglecting the influence of spreading.

The influence of friction coefficient on the forward slip in cold longitudinal flat rolling for specimens made from EN AW-6063 aluminium is shown in the diagram (Fig. 3). The calculated forward slip increases with an increase in μ friction factor. The maximum value of the forward slip was obtained for friction factor $\mu = 0.29$ (kerosene as a lubricant of rolls) and minimum for $\mu = 0.22$ (mineral oil as a lubricant).

Table 4. Values of roll bite angles, friction factor and forward slips calculated in different conditions of rolling

Lubrication:	α_{ch} [^{0}]	μ	S_w from Fink's formula (1), [%]	S_w from Drezden's formula (5), [%]	S_w from Vinogradov's formula (6), [%]
extraction naphtha	15,58	0.29	27.30	27.60	19.30
kerosene	16,30	0.28	23.50	18.40	19.20
rapeseed oil	14,21	0.25	8.86	10.49	6.78
motor oil	12,81	0.23	7.20	7.42	4.83
mineral oil	12,16	0.22	5.13	5.39	5.71

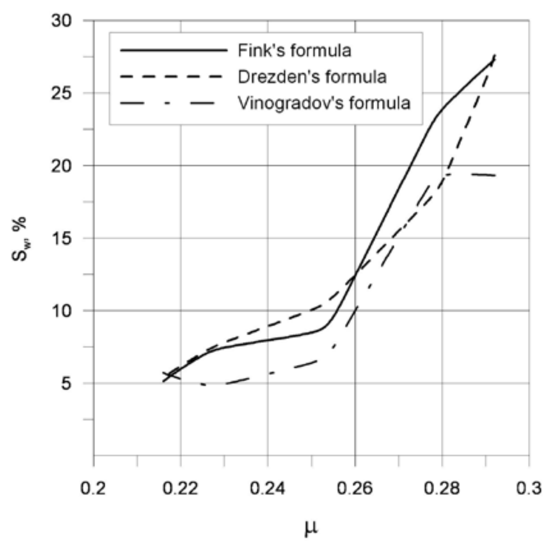

Fig. 3 Influence of friction coefficient on the forward slip in cold longitudinal flat rolling for specimens made from EN AW-6063 aluminium.

Summary

On the basis of investigations carried out into cold longitudinal rolling of flat bars made from EN AW-6063 aluminium, the following can be stated:

1. 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 μ friction factor, and in all the considered cases they were the greatest for Drezden's formula (5), whereas the lowest values were obtained for Vinogradov's formula (6).

2. Forward slip increases with an increase in μ friction factor. The maximum value of the forward slip was obtained for friction factor μ = 0.29 (kerosene as a lubricant of rolls) and minimum for μ = 0.22 (mineral oil).
3. Fink's (1), Drezden's (5) and Vinogradov's (6) formulae, used for calculating forward slip in longitudinal rolling can be applied in engineering practice. Their knowledge is necessary to determine the workpiece velocity in the exit zone of deformation.

References

[1] Wusatowski Z.: Fundamentals of rolling, Śląsk, Katowice, 1969.

[2] Lange K.: Handbook of metal forming, McGraw-Hill Book Company, 1985.

[3] Miłek T., Kopacz Z.: Evaluation of the possibility of diameter reduction in Mt 1020 steel tubes by rolling on the WPM-120 cold profile eccentric rolling machine, 24th Int. Conf. on Met. and Mat., Brno (2015) 377-382.

[4] Sińczak J. et al.: Metal forming processes, AKAPIT, Kraków 2001 (in Polish).

[5] Kowalik M., Trzepieciński T.: Experimental and numerical study of longitudinal cold rolling of the shafts, Steel Res. Int. se 14th Int. conf. Metal Forming (2012) 63-66.

[6] Engler O., Schäfer C., et al.: Flexible rolling of aluminium alloy sheet—Process optimization and control of materials properties, J. Mater. Process. Technol. 229 (2016) 139-148. https://doi.org/10.1016/j.jmatprotec.2015.09.010

[7] Tabary P.T., Sutcliffe M.P.F., Porral F., et al.: Measurements of friction in cold metal rolling, ASME J. Tribology 118 (1996) 629-636. https://doi.org/10.1115/1.2831584

[8] Gjønnes, L., Andersson B.: Mechanisms of surface deformation during cold rolling of aluminium, J. Mater. Sci. 33 (1998) 2469-2476. https://doi.org/10.1023/A:1004328513471

[9] Gerasimov D., Biba N. Stebunov S., Kadach M.: Implementation of a dual mesh method for longitudinal rolling in QForm V8, Mater. Sci. Forum 854 (2016) 158-162. https://doi.org/10.4028/www.scientific.net/MSF.854.158

[10] Ścieżor W., Mamala A., Kwaśniewski P.: Analysis of properties of selected aluminium alloys, obtained by twin roll casting method and subjected to cold rolling process, Key Eng. Mat. 641 (2015) 202-209. https://doi.org/10.4028/www.scientific.net/KEM.641.202

[11] Grydin O., Bondarenko S., Stolbchenko M., et al.: Rolling of flat Aluminum strips with tailored mechanical properties, Mater. Sci. Forum 854 (2016) 87-92. https://doi.org/10.4028/www.scientific.net/MSF.854.87

[12] J.R. Davis, Aluminum and Aluminum Alloys, ASM Specialty Handbook, ASM International, Ohio, 1993.

[13] Hirsch J.: Aluminium in innovative light-weight car design, Mater. Trans. 52 (2011) 818-824. https://doi.org/10.2320/matertrans.L-MZ201132

[14] Czarny R.: Plastic lubricants, WNT. Warszawa, 2004 (in Polish).

[15] Information on http://www.chem-rozlew.com/

[16] Information on http://www.orlenoil.pl/

[17] Information on http://www.total.com.pl/

[18] Information on http://www.basiccomponents.com.pl/