INFLUENCE OF PROCESS PARAMETERS ON THE FRICTION COEFFICIENT IN AlMg3 ALLOY STRIP IRONING DRAWING TEST

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Abstract: *Presented in this paper are the results of experimental investigations of influence on friction in the stripe ironing process with double thinning. Applied was modified mathematical model for evaluating influence of lateral force, contact pressure and average absolute roughness height on friction coefficient. Classical model in not suitable for small lateral and drawing forces, and give unreal negative friction coefficient values. Previously proposed and applied here, modified model is more appropriate. Calculated friction coefficient values in that model are more according to reality. 20 mm wide and 3.0 mm thick strips of AlMg3 alloy sheets were used in the single and three-phase process with a maximum thinning deformation of 27%. Appropriate lubricating grease was used in conditions of lower speed of 20 mm/min. Three phase process was realized with variable lateral force of 4, 8 and 12 kN. The applied experimental test procedure enables the precise quantification of lateral force, contact pressure and roughness influence on friction to be established. Test also enables evaluation of lubricants quality.*

Keywords: *modified stripe ironing test, Al alloy, friction coefficient.*

1. INTRODUCTION

Ironing is metal forming process which combine characteristics of sheet metal forming and massive (bulk) forming. Thinnig strain reach over 25%, and contact pressure over 1000 MPa [1]. It is well known application of the ironing process in manufacturing different kinds of thin walled cans. World annual production (especially for beverage cans) are more than billion pieces. In the tribologycal sense, ironing process is one of the most severe, owing to the high surface expansion, large plastic strains and high normal pressure at the tool-workpiece interface. Considering previous notice more researchers still interested in ironing. During the last decade significant attention is paid on investigation of environmentally friendly lubricants application [1, 2, 3].

In order to quantify the performance of the individual lubricants, a different experimental test methods has been developed. Wide applying have double (or single) sided thinning stripe ironing test in different variations [4, 5, 6, 7, 8]. Following mathematical model is mainly so called Schlosser model [4]. Despite its evident deficiency or inaccuracy was indicated yet in article [5], and in [9] detailed motivated, however that model is applying even in recent extensive researches [8]. In authors investigations [9, 10, 11] proposed was different, or corrected mathematical model usable in all conditions with real results.

In this paper presented is another verification of above mentioned authors model. It is experimental investigation of process parameters (lateral force, nominal pressure, roughness) influence on friction coefficient in double sided ironing of AlMg3 alloy stripes.

2. EXPERIMENT

2.1 Device description, physical and mathematical model

The special device for physical modeling the symmetrical contact between the sheet strip and die was used for experimental investigation (Fig. 1 and Fig. 2). The sheet metal sample (strip 2) is placed in the jaws (1) vertically. In the initial phase the thinning makes such that the right-hand sliding tool element (6 right) acts upon the strip by lateral force F_D (Fig. 2). Due to the fixed left side tool element (6 left) and the action of right element, the even double sided ironing of the strip is realized.
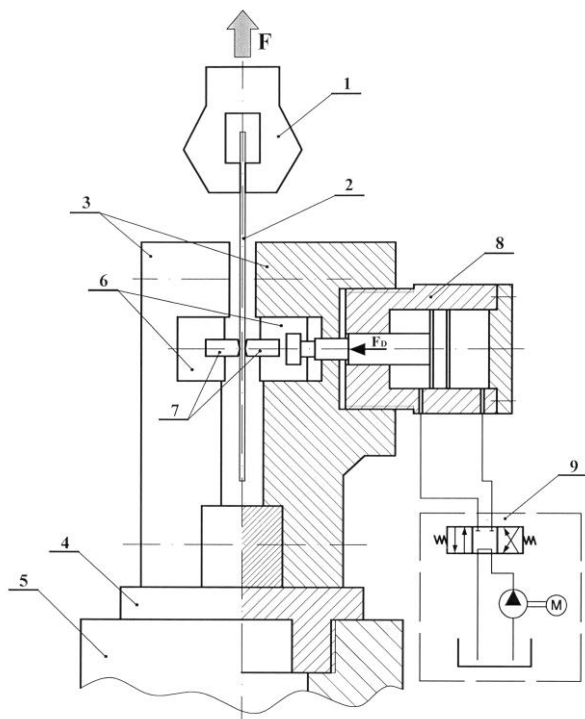

Figure 1. Experimental device scheme

After the initial thinning deformation was realized, the tensile force F (Fig. 2) begins to act, and the ironing process continues until the sample length is executed. The main action of

the ERICHSEN 142/12 laboratory hydraulic press is used as the tensile force across the range of 0-20 kN at speed of 20 mm/min. The lateral force is realized by the hydro-cylinder (8). The maximum range of the lateral force is 0-50 kN. The piston pushes right hand element (6) which is coupled to the sliding element (7). The hydro cylinder (8) is powered by the independent hydraulic aggregate (9), which contains the filter, electric motor, pump, two position directional control valve, adjustable control valve for lateral force and manometer. The data acquisition system measures drawing force dependence on the sliding length or time and the constant intensity of lateral force [10, 11, 12].
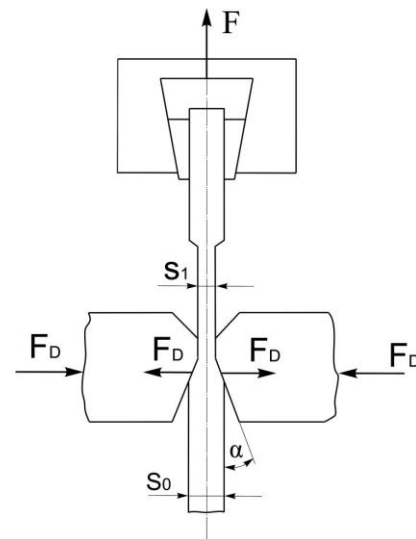

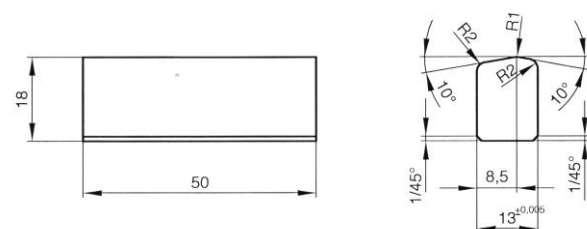
Figure 2. Forces acting scheme

Figure 3. Tool elements geometry

Geometry of the tool elements are shown at Fig. 3. Physical appearance of elements and assembly can be seen at Fig. 4a and 4b.
For the contact elements material chosen was alloyed tool steel X160CrMoV12 with 62 HRC hardness after thermal treatment. Active surfaces are fine ground and polished with average absolute roughness height $R_a \approx 0,06$ µm.

$$\overline{p} = \frac{0,03015 \cdot F + 0,2394 \cdot F_D}{18,03(3,06 - s_1)} \qquad (4)$$

2.2 Strip material properties

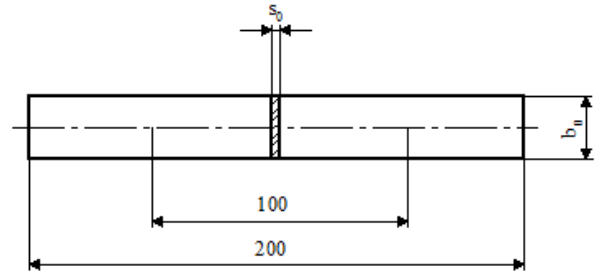Geometry of the strip is shown in Fig. 5 and Tab. 1.

Figure 5. Strip geometry

Table 1. Strip dimensions

Material		l_0 [mm]	b_0 [mm]	s_0 [mm]
AlMg3	min	100	17,79	3,05
	average	100	18,03	3,06

For experimental investigations in this paper chosen was the aluminium alloy AlMg3. Specimens for mechanical properties were prepared accordin to standards SRPS EN ISO 6892 - 1.2012. Determined material characteristics are shown in Tab. 2.
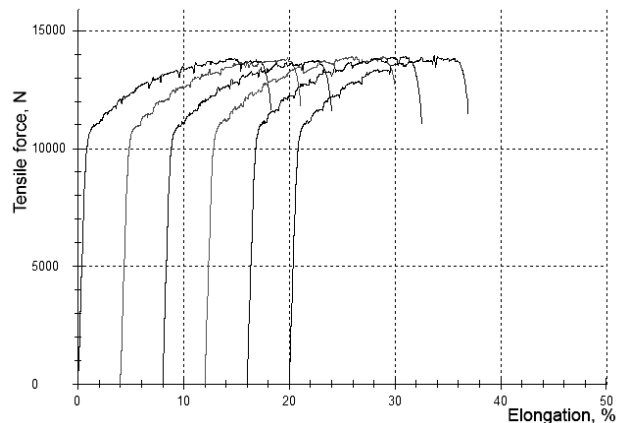

Figure 6. Tensile force - strain curves

Experimental tensile force - strain curves (Fig. 6) were obtained for six specimens with excellent repeatability. As can be seen, force

Figure 4a. Tool elements physical appearance

Figure 4b. View of tool assembly

According to established model [9] obtained are following formulas for friction coefficient and average calculated (nominal) pressure:

$$\mu = \frac{F}{2aF_D \cos^2 \alpha + F\frac{\sin 2\alpha}{2} + 2(1-a)F_D} \qquad (1)$$

$$\overline{p} = \frac{F \sin^2 \alpha + aF_D \sin 2\alpha}{b(s_0 - s_1)} \qquad (2)$$

Parameter "a" is determining distribution of side force F_D between inclined and small vertical contact surface and his value is in the range 0 to 1. It was adopted a=0.7 in this case. Change of parameter "a" is very small (about 1%). Inclination angle α is 10° as can be seen in Fig. 3.

Formulas (1) and (2) with current data for this experiment, are:

$$\mu = \frac{F}{0,171 \cdot F + 1,958 \cdot F_D} \qquad (3)$$

(or stress) curves have oscillatory dependence on strain which is common for Al alloys.

In Tab. 2 $R_{p0.2}$ is yield strength, R_M is tensile strength, A is percenage elongation et fracture and "n" is strain hardening exponent.

Table 2. Mechanical properties

Material		$R_{p0,2}$ [MPa]	R_m [MPa]	$R_{p0,2}/R_m$	A [%]	n
AlMg3	min	190,16	253,17	0,751	15,17	0,144
	aver.	191,31	253,56	0,754	16,29	0,150

3. RESULTS AND DISCUSSION

Within results of this experiment, diagrams of tensile forces are presented first (Fig.7, Fig.8, Fig.9). In the first case (Fig. 7) used are one phase process. Each stripe sliding process needs separate specimen with appropriate lateral force (F_D). Values are chosen according to empirical recommendation (4kN; 8 kN and 12 kN). Lateral force of 12 kN is above limiting and strip break occurs at sliding path of about 50 mm.
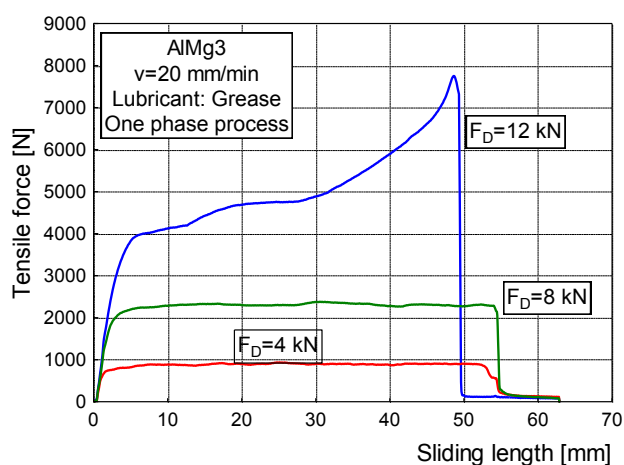

Figure 7. Tensile force vs sliding length curves

Fig. 8 represents more severe conditions. There is three phase process realized on the single specimen. First sliding is performed with lateral force of 4 kN at the path length of about 54 mm. Second phase is performed on the same specimen but ironing starts 20 mm after stripe path beginning. Lateral force was higher: 8 kN. Third sliding passage take place on the same strip also, after 40 mm path. Conditions was to severe and brake occur after about 18 mm sliding length.
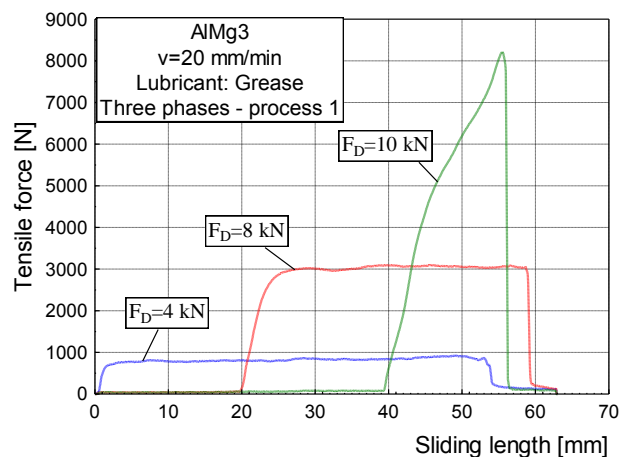

Figure 8. Tensile force vs sliding length curves

Lubricant in the process was grease (signed PRESS 626) of domestic producer, intended to drawing operations. Kinematic viscosity of that lubricant is 330 mm^2/s at 40° C.

Fig. 9 shows tensile force diagrams for three phase ironing process with constant lateral force of 8 kN in each phase. Second and third phase starts with 20 mm offset like in previous case. Sliding process is relatively smooth and no brake occurs.
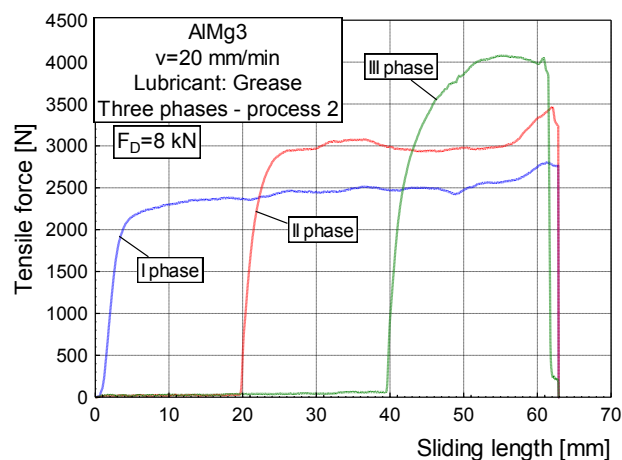

Figure 9. Tensile force vs sliding length curves

Figure 10. Strips after multi phase ironing

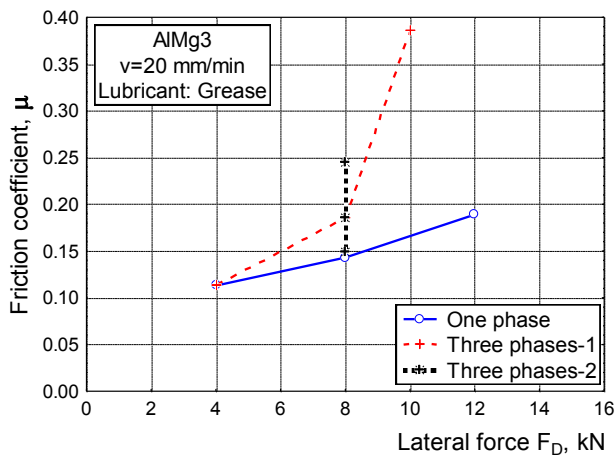In Fig. 10 is the strips appearance after multi phase ironing.

Figure 11. Friction coefficient dependence on lateral force

In this study investigated are the influences of lateral force, calculated (nominal) pressure and average roughness on the friction coefficient (Fig. 11, 12 and 13).

Dependences given at the. Fig. 11 determined are according to terms (1) and (3). For tensile force F intensities was adopted average values. For one phase process friction coefficient (μ) have relatively small values, even in case of 12 kN lateral force where break occurs.

Diagrams for three phase processes clearly shows that μ increase, and it is in accordance with heavier process conditions. Especially in the three phase process with lateral force increasing (proc. 1 in Fig. 11), μ reached maximum value.
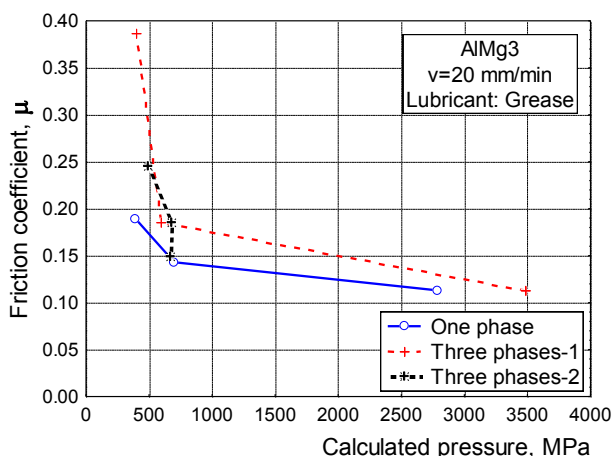

Figure 12. Friction coefficient dependence on calculated pressure

Fig. 12 shows friction coefficient dependence on calculated pressure according to terms (2) and (4). For that parameter must be noticed that it is only calculated or nominal

parameter, which inversely depends on strip thinning strain. Because of that, pressure values are reached unreal intensities for very small thinning. So, calculated pressure need to be considered like parameter related to thinning strain, rather than real pressure.
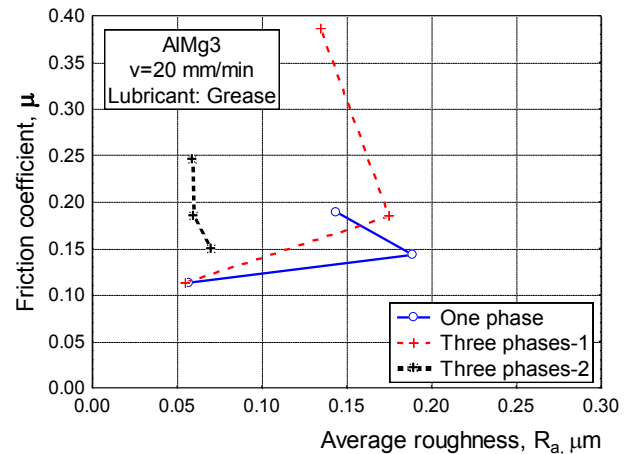

Figure 13. Friction coefficient dependence on average roughness

For diagrams at Fig. 12 need to be notice that the process starts at the high calculated pressure values and goes to lower values (from right to left side of diagram). As can be seen from Fig. 12 friction coefficient increasing with thinning strain increasing, or calculated pressure decreasing.

Relation between friction coefficient and average roughness R_a (Fig. 13) gives somewhat unexpected values in one phase and three phase (process 1) cases. In third stage μ increases while R_a decreases. Expectation is opposite. Possible explanation is in the way of μ calculation and R_a determination. μ is calculated according to formulas (2 and 4) and depends only of tensile force F and lateral force F_D . In other side R_a is determined experimentally, by measuring. Also, it is possible to occur polishing effect in the third stage and deceasing R_a and the calculated higher μ values at the same time.

4. CONCLUSIONS

Two types of analysis was accomplished in this study. First was application and testing of authors previously proposed formulas for coefficient of friction and calculated pressure

determination in strip ironing test. Results of this study, like in some other cases, confirms usableness of proposed formulas and model, in the lubricants evaluation par example. Proposed formulas have special significance in conditions of relatively small tensile and lateral forces intensities. That is the case in aluminium ironing process.

Second was particular experiment with intention to evaluate process parameters influence on the friction coefficient. Results shows the following annotations:

a) increasing of lateral and drawing forces both, influence on friction coefficient increasing (process type 1),

b) thinning strain increasing, i.e. calculated (nominal) pressure decreasing, caused friction coefficient increasing,

c) known influence of average roughness R_a is confirmed, but polishing effect occurred in the third stage of processes with high lateral force intensities.

For further evaluations of different influences on the Al alloys ironing process (especially multi phase) needs to continue extensive experiments in different conditions.

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