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TWO-PHASE IRONING PROCESS IN CONDITIONS OF ECOLOGIC AND CLASSIC LUBRICANTS APPLICATION

Milan DJORDJEVIC[1,*], Srbislav ALEKSANDROVIC[1], Vukic LAZIC[1], Dusan ARSIC[1], Milentije STEFANOVIC[1], Dragan MILOSAVLJEVIC[1]
[1]Faculty of Engineering, University of Kragujevac, Serbia
*Corresponding author: e-mail: tpolab@fink.rs

Abstract: *Presented In this paper are the results of experimental investigations of the type of lubricants influence on the ironing process. For the realisation of the strip ironing test with double thinning a device was created. In the two-phase process with a maximal thinning deformation of approximately 35 %, strips of 2.5 mm-thick low carbon steel sheets were used. Side forces of 10, 15 and 20 kN were used. Sliding speed was 100 mm/min. Experimental estimates of three lubricants are presented and compared in this paper. Most important is ecologically acceptable solid dry so called single-bath lubricant. In addition, a phosphate layer with mineral oil was applied, as was mineral oil with EP additives only. The criterion for the lubricants estimates was the change in the friction coefficient during the sliding process. The applied device and test procedure enables to evaluate different influences in double phase ironing process. Also enables the clear differences between the lubricating properties of the investigated lubricants to be established.*

Keywords: *two-phase ironing process, friction coefficient, ecological lubricant.*

1. INTRODUCTION

Lubricants have the status of potentially dangerous pollutants and that has been confirmed by the legal regulations [1]. Classical lubricants, nevertheless mainly ecologically harmful, can provide good results in applications, with decades of development and using experience [2]. Also, classical lubricants have low price. Unfortunately, economic survival is oftenly more important than preservation of the environment. The new, ecological lubricants are still in the process of proving in laboratories and industrial practice as well. The recent development of dry lubricants without a conversion coating has attracted special attention. There are two types: the so-called dual-bath and single bath lubricants. Dual-bath lubricants form two layers on the working surface [1]. With single-bath lubricants, attempts have been made to create a single layer on the part’s surface in much simpler procedure [1,3]. In addition to dual-and single-bath lubricants, boric acid has also been used in various investigations [4]. The disadvantage of boric acid is its tendency to absorb moisture from the air, which significantly worsens its anti-frictional properties [5]. Evaluations of a series of lubricants performances is presented in several chosen papers. In the ironing test, applied in [6] and [7], a cup-shaped specimen made of thin sheets is used to evaluate the lubricants. A survey of several tests in production conditions for investigating lubricants in the sheet-metal forming processes is presented in [8]. The double-sided single-phase ironing test was used for classical lubricant evaluation in [9]. In [10] complex tribological influences were investigated in strip sliding test.

The fundamental goal of this paper is to conduct a comparative investigation of a single-bath lubricant with two conventional lubricants in specific two-phase process. The experimental device was designed using a methodology based on monitoring the friction coefficient during the process. Main contribution in this study is more proofs for additional affirmation of ecological lubricants use in industrial application.

2. EXPERIMENT

2.1 Device, tooling and procedure

The ironing test with double-sided thinning of the metal sheet, was applied in this experimental investigation, as depicted in the scheme presented in Figure 1. The details of the device are given in Figure 2. Physical appearance is shown in Figure 3. The sheet metal sample (strip 13) is placed in the fastening jaws (12) vertically. In the initial phase, the thinning occurs such that the right-hand moving sliding element (10) acts upon the strip by lateral force. Due to the fixed side element (11) and the action of the sliding element (10), the even double-sided ironing of the metal strip is realised. After the initial thinning deformation was realized, the tensile force F 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 measurement range of 0-20 kN at a speed of 100 mm/min. The lateral force is realised by the hydro-cylinder (7). The measurement range of the lateral force is also 0-20 kN. The piston (8) pushes the element (9), which is coupled to the sliding element (10). The hydro-cylinder (7) is powered by the independent hydraulic aggregate, which contains the filter (1), pump (2), electric motor (3), valve for pressure and lateral force adjustment (4), manometer (5) and two-position directional control valve (6). The data acquisition system measures the tensile force dependence on the sliding length or time and the constant intensity lateral force.

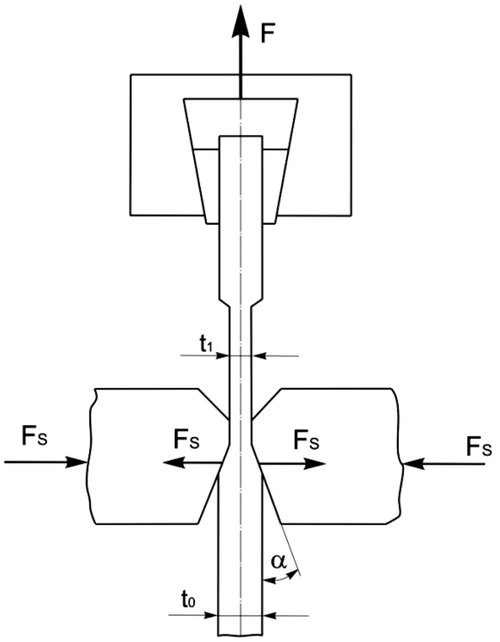

Figure 1. The tribological model: Scheme of the contact between the sliding elements and sample

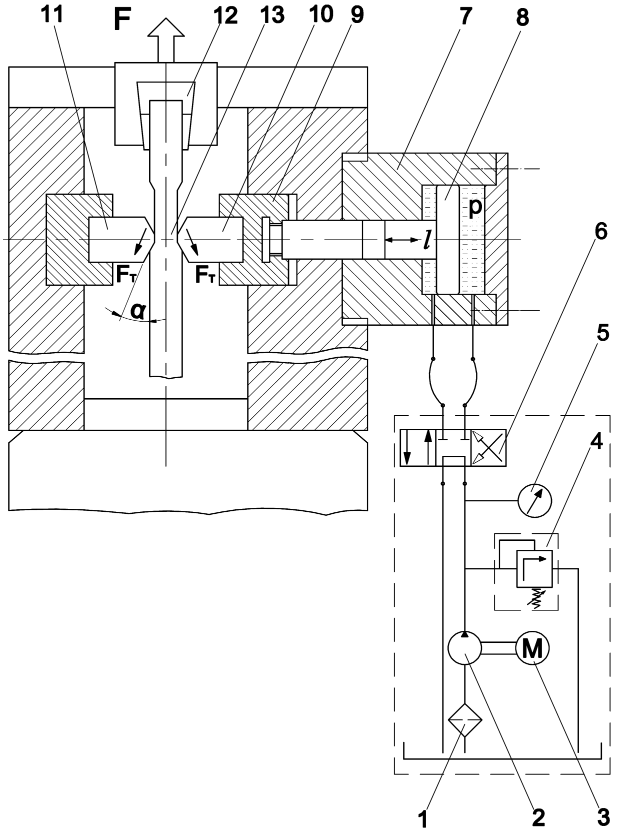

Figure 2. Scheme of the experimental device

Sensors are placed within the ERICHSEN press. The voltage signals, after amplification and filtering, are input into the A/D converter and, converted into the files describing the tensile force dependence on the strip length using the corresponding software.

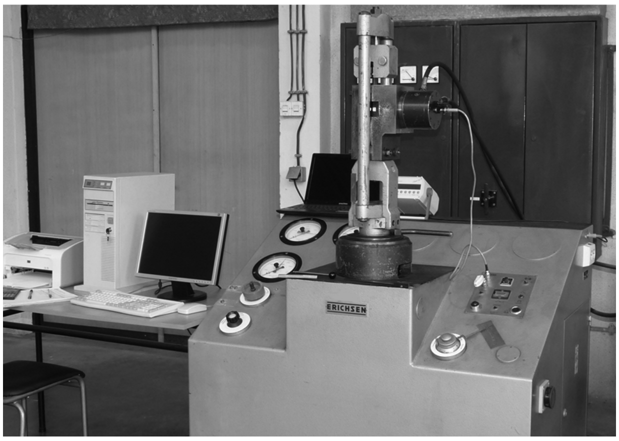

Figure 3. Physical appearance of the experimental device

The geometry of the lateral sliding element is presented in Figures 4a and b. These parts are made of the X210Cr12 tool steel (EN ISO 4957) without the surface coating and have a hardness of HRC 60-62. The surface is polished, and the roughness is expressed by the average absolute roughness height from the centre line R_a (0.08 µm), divided by the reference length of 5 mm.

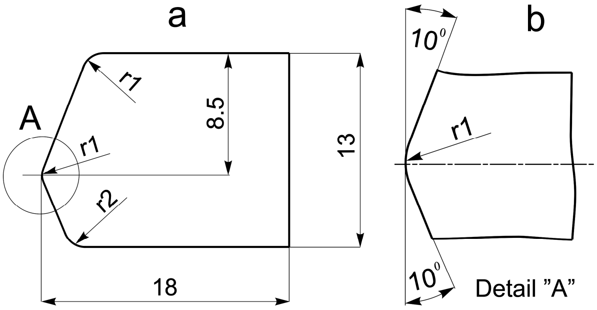

Figure 4. Geometry of the lateral sliding element

The samples are strips of DC04 low-carbon steel sheets with a thickness of 2.5 mm, an average width of 20.2 mm and a length of 200 mm. Its main mechanical properties and properties of formability are given in Table 1 (R_p – yield strength, R_M – tensile strength, A – elongation at fracture, n – strain hardening exponent, r – coefficient of normal anisotropy). The surface roughness of the sheets, expressed by the average absolute roughness R_a, is 1.03 µm over the referent length of 5 mm.

Table 1. Material properties

Steel DC04				
R_p [MPa]	R_M [MPa]	A [%]	r [-]	n [-]
185.2	284.5	35.3	1.68	0.215

2.2 Lubricants

Three lubricants, i.e., three contact conditions, are used in this analysis. The first is the classical phosphate layer of zinc phosphate, with a thickness of approximately 10 µm, over which the mineral oil was deposited. The oil was applied considering the less strict requirements for the ironing process with respect to cold forming. This lubricant was denoted as L1. The second lubricant is an environmentally friendly lubricant, and its evaluation relative to the two classical lubricants represents the essence of this study. This lubricant is the single-bath double-layered lubricant and is dissolvable in water.

The preparation and deposition of the lubricant consists of the following phases:

a) Sand-blasting or chemical treatment of the work piece.
b) Dilution of the lubricant in demineralised water.
c) Deposition of the lubricant by dipping.
d) Drying.

In this experiment, instead of sand-blasting, chemical treatment in acidic solution was used for the preparation of the samples surfaces. The lubricant manufacturer recommends submerging the parts in a 15 % aqueous solution of sulphuric acid (H_2SO_4) for 10 min and then rinsing with hot demineralised water. Following the rinsing, the parts are submerged in 10 % hydrochloric acid (HCl) solution for 5 min, followed by rinsing with hot demineralised water. Lubricant deposition is performed by dipping the parts into the lubricant bath, where the permissible temperature range is from 50 °C to 70 °C. The deposition can also be performed successfully under industrial conditions using automated lines. The drying of the deposited lubricant should be performed using hot (100 °C) air for 15 min. In this way, the two-component dry layer of lubricant is formed. Due to its hygroscopic properties, the created lubricating layer should be used the same day. In the case of storage, under conditions of increased air moisture, drying should be repeated immediately prior to the forming process.

The lubricant formed according to the described procedure was denoted as L2.

The third lubricant is classical mineral oil, containing the EP sulphur-based additives, which uses in thin sheets forming. Its density and kinematic viscosity are 0.93 g/cm^3 and 100 mm^2/s, respectively, at 40 °C. The oil was deposited in sufficient quantities onto the surface of the previously degreased sheet. This lubricant was denoted as L3. It should be mentioned that the same oil was used as the additional lubricant over the phosphate layer (L1).

2.3 Test conditions

As already mentioned, uncoated DC04 steel strips (2.5 mm thick), were used in this experiment. The three lubricants which were described were applied, with emphasis on lubricant L2. The strip sliding speed was 100 mm/min.

Considering the material properties, three lateral force intensities were selected: 10, 15 and 20 kN. The effect of the lateral forces can be seen in Figure 5, which shows the dependence of the thinning strain on the lateral force intensity. Lateral forces of 10 kN, 15 kN and 20 kN yield an average strain of 7 %, 14 % and 20 % respectively at first phase. At second phase thinning strains are 11 %, 25 % and 35 %. As expected, the lubricant has a negligible influence during the initial thinning, as seen from Figure 5.

This paper presents the results of the two–phase ironing process at a sliding length of approximately 60 mm at first, and 40 mm at second phase. During the process, the variation of the tensile force in terms of the strip length was measured simultaneously for each sample. The variation of the friction coefficient during the process was then defined, according to consideration given in [11]. In second phase of the process the working conditions are more severe. Tensile forces, i.e. contact pressures, have higher intensities. Tribological phenomena such as galling, can occur in sliding process over previously changed sample surface.

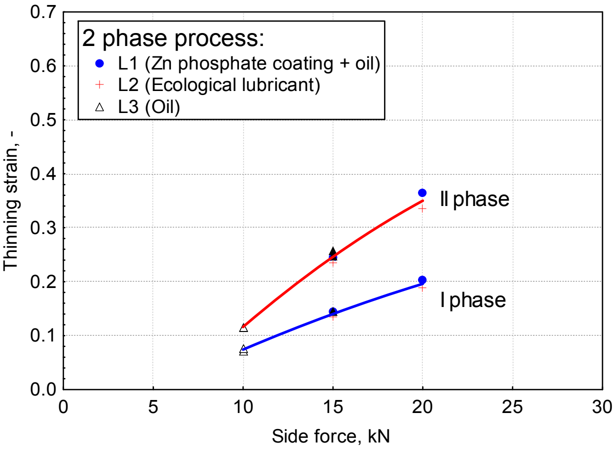

Figure 5. Thinning strain dependence on side force for different lubricants

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figures 6 to 10 present the dependences of the tensile forces on the sliding length for all three types of lubricants and for the three constant intensities of the side forces. Each force curve is actually a set of the discrete values, a numerical series with approximately 900 values, for the 60 mm sliding length, and 600 values for 40 mm length.

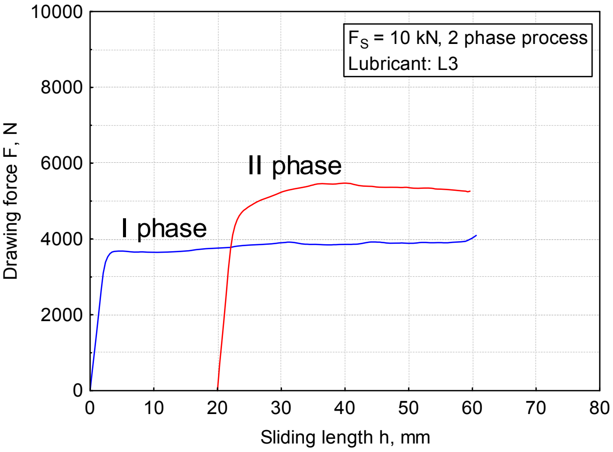

Figure 6. Tensile force dependence on sliding length for lubricant L3

In the case of lubricant L3, the tensile force intensity is significantly increased with side force increasing. At side forces F_S > 10 kN there is impossibility of performing the ironing process in second phase, due to very strong friction with rough galling. These findings indicate the insufficient lubricating properties of used oil (L3) and favourable lubricating properties of lubricants L1 and L2.

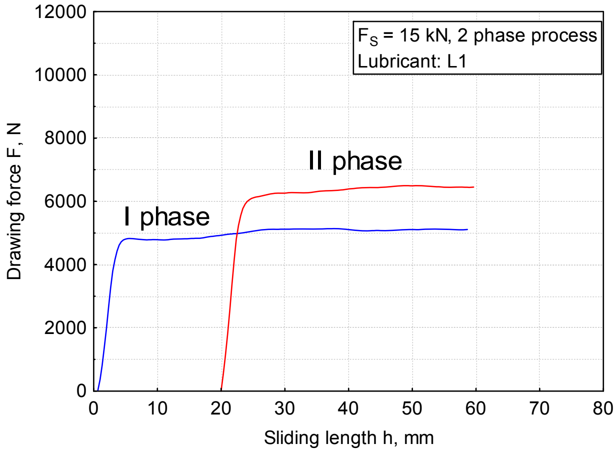

Figure 7. Tensile force dependence on sliding length for lubricant L1

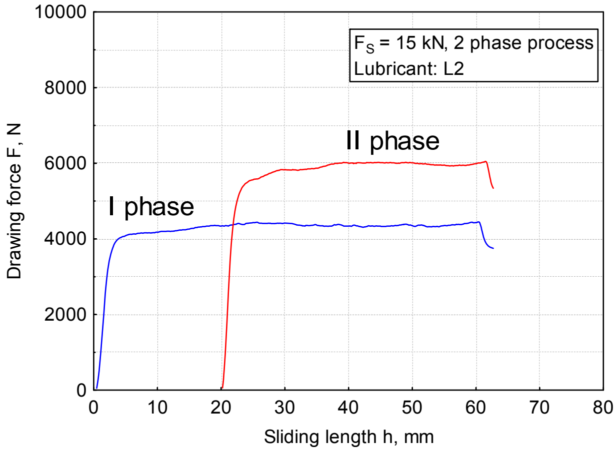

Figure 8. Tensile force dependence on sliding length for lubricant L2

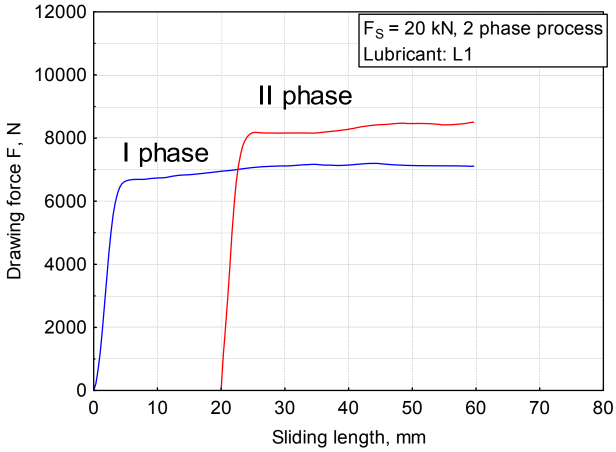

Figure 9. Tensile force dependence on sliding length for lubricant L1

This is the reason for using lubricants L1 and L2 only in further course of the experiment. It is interesting that the tensile forces for the phosphate layer with oil (L1) are somewhat higher, than those for the environmentally friendly lubricant (L2). This tendency appeared in side forces of 15 kN and 20 kN both.

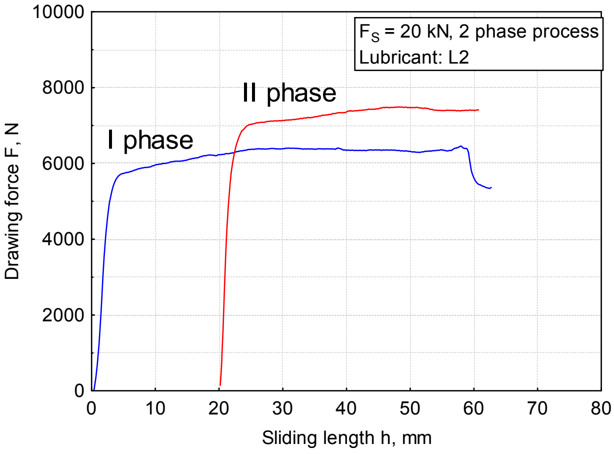

Figure 10. Tensile force dependence on sliding length for lubricant L2

The friction coefficient variation was calculated for each tensile force dependence on the sliding length, Figs. 11 to 14.

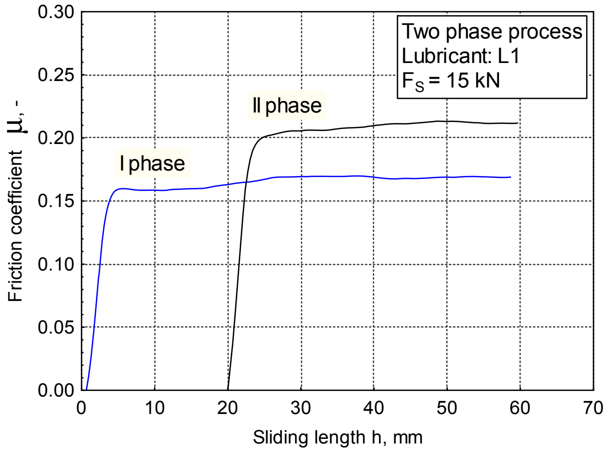

Figure 11. Friction coefficient dependence sliding length for lubricant L1

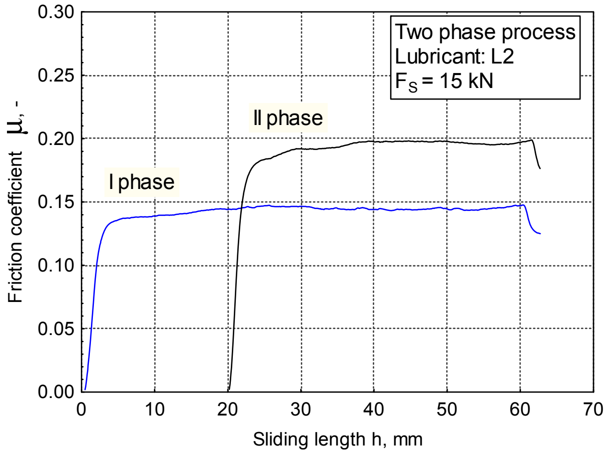

Figure 12. Friction coefficient dependence sliding length for lubricant L2

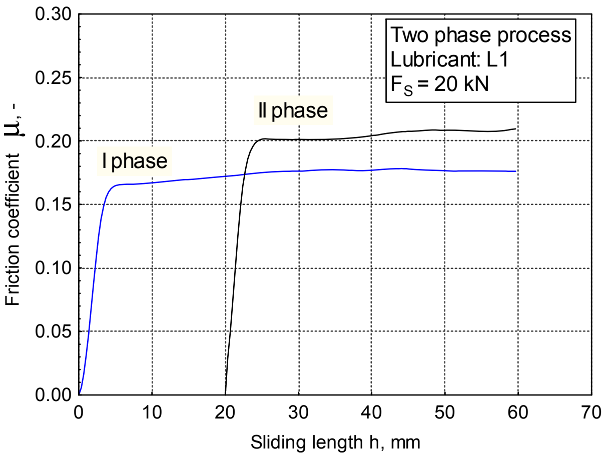

Figure 13. Friction coefficient dependence sliding length for lubricant L1

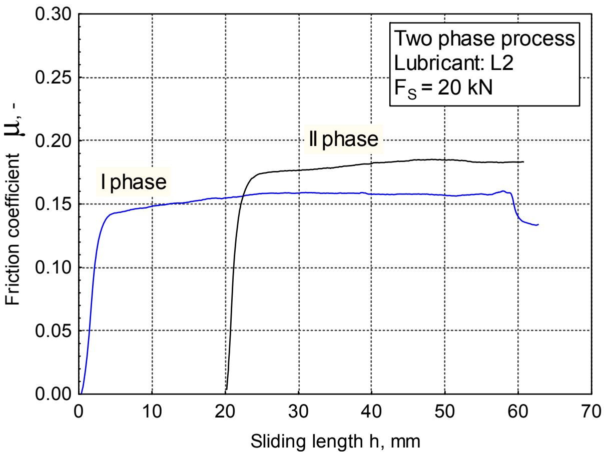

Figure 14. Friction coefficient dependence sliding length for lubricant L2

The friction coefficient variation for the phosphate layer with mineral oil was applied (L1) is presented in Figures 11. and 13. The values are relatively low, ranging from 0.2 to approximately 0.22 in second phase. The increase in the lateral force from 15 to 20 kN does not significantly influence the increase in the friction coefficient.

The findings for the environmentally friendly single-bath lubricant (L2) are presented in Figures 12 and 14. Its friction coefficient is the lowest (0.175 to 0.2 in second phase).

It is clear that the lubricating properties of the environmentally friendly lubricant (L2) are good and that it can replace the others lubricants used in this study.

4. CONCLUSION

After the consideration of the results of this experimental investigation the following conclusions can be adopt:

- The device for strip ironing test with double-sided thinning used in this experiment is convenient for estimating the performance of lubricants in two phase processes with medium compressive forces and a thinning deformation of the low-carbon steel sheets of up to 25 %. The methodology, which is based on measurements of the tensile and lateral forces is simple and provides clear results.
- The friction coefficient was set as the main criterion. The obtained values correspond to the process characteristics and can be used to test the lubricants performances.
- Three lubricants were tested: two classical lubricants and one environmentally friendly, water-soluble single-bath lubricant. The zinc phosphate coating with oil has the sufficient lubricating properties, based on low values of the tensile forces and the friction coefficient. Those are the reasons for frequently application of the phosphate coating in the ironing processes. Problems of application of the phosphate coating, however, are in the phosphatization process, which is toxic both for humans and the environment.
- Mineral oil with EP additives is not convenient lubricant for such kind of process.

The environmentally friendly lubricant tested exhibits a favourable values and distribution of the friction coefficient during the process. It is the reason for conclusion that used ecological lubricant can replace toxic zinc phosphate coating in similar contact conditions.

Future research should include tests with three or more phase ironing processes, in which the working conditions are much more severe, and the lubricant is expected to possess superior properties.

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