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INFLUENCE OF LUBRICANTS ON WEAR RESISTANCE OF ALUMINUM ALLOY STRIPS SERIES 2XXX

WPŁYW ŚRODKÓW SMARNYCH NA ODPORNOŚĆ NA ZUŻYCIE BLACH ZE STOPU ALUMINIUM SERII 2XXX

The article presents a properly planned and designed tests of the abrasive wear resistance 2024 aluminum alloy strips under friction conditions involving various lubricants. Test were focused on the selection of the best lubricant for use in industrial environment, especially for sheet metal forming. Three lubricants of the Orlen Oil Company and one used in the sheet metal forming industry, were selected for tests. Tests without the use of lubricant were performed for a comparison. The tester T-05 was used for testing resistance to wear. As the counter samples were used tool steel - NC6 and steel for hot working - WCL, which are typical materials used for tools for pressing. The results are presented in the form of the force friction, abrasion depth, weight loss and coefficient of friction depending on the lubricant used and the type of counter samples. The results allowed for predicting set lubricant-material for tools which can be applied to sheet metal made of aluminum alloy 2024.

W artykule przedstawiono wyniki badań odporności na zużycie blach ze stopu aluminium serii 2024 w różnych warunkach smarowania. Badania były ukierunkowane na wybór najlepszego środka smarnego do zastosowania w warunkach przemysłowych, przede wszystkim do tłoczenia blach. Do badań wytypowano trzy środki smarne firmy Orlen Oil oraz jeden środek smarny stosowany w przemyśle do tłoczenia blach. Dla porównania wykonano również badania bez użycia środka smarnego. Do badań odporności na zużycie wykorzystano tester T-05. Jako materiały przeciwpróbek zastosowano stal narzędziową NC6 oraz stal do pracy na gorąco WCL, będące typowymi materiałami wykorzystywanymi na narzędzia do tłoczenia. Wyniki badań przedstawiono w postaci zależności siły tarcia, głębokości wytarcia, ubytku masy i współczynnika tarcia od zastosowanego środka smarnego i rodzaju przeciwpróbki. Wyniki badań pozwoliły na wytypowanie najlepszego, spośród badanych, zestawu środek smarny-materiał na narzędzia, do tłoczenia blach ze stopu aluminium z gatunku 2024.

1. Introduction

One of the key issues in the analysis of metal plastic forming processes is the external friction on the contact surface between the tool and plastically deformed metal. Terms of friction have a significant impact on the course of plastic deformation, including the functional properties of the product and the lifetime of tools. Tangential components associated with the impact of the working surface of the tool to the surface plastically shaped metal have a significant impact on the field distribution and state of stress and strain. The friction forces affect the distribution inhomogeneity of the stress field in a plastically deformable metal, which results in inhomogeneity of the deformation, and at too high frictional resistance leads to decohesion.

A commercially available is very wide assortment of lubricants derived from domestic and foreign suppliers. At the same time, both the company and the various research centers carry out research aimed at improving lubricants and thus broaden the fields of application of new or improved lubricants, including the presswork.

The study was carried out properly planned and designed test the wear resistance of the friction strip of aluminum alloy grade 2024. Research carried out in different friction conditions and using different lubricants have to search for the effects and relationships, enabling selection of the best lubricant to obtain more favorable conditions for conducting plastic forming processes in the aerospace, automotive and military applications where the 2024 alloy is used. In the literature there are, indeed, results in wear resistance of aluminum alloys 2XXX and composites based on these alloys [1-4] but they concern primarily the mechanisms and phenomena occurring at the interface between the material-tool without a focus on the leading role lubricants.

Similar studies, for presented in this article were made on strips and steel pipes coated Al-Si [5-7].

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2. Experimental technique

Three lubricants of Orlen Oil Company were chosen, designated in the following as A, B, C and one lubricant used in the industry for sheet metal, indicated as D (Fig. 1). For comparison, the study also carried out without the use of lubricants. Lubricants A, B, C are designed specifically for their potential use for pressing of selected species of aluminum alloys.

a) b) c) d)

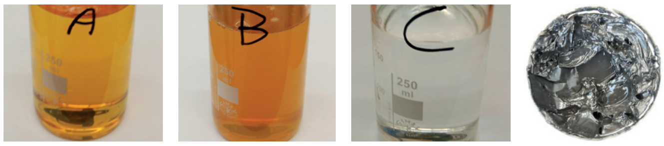

Fig. 1. Lubricants used in tests
a) lubricant A, b) lubricant B, c) lubricant C, d) lubricant D

Lubricant A

Cutting-cooling oil produced on mineral oil base. Contains additives increasing film strength lubricant additives increasing traction and facilitating process of cleaning items after pressing. It is used to pressing the difficult geometry of the elements and in the cutting process.

Lubricant B

Cutting-cooling oil produced on high-grade mineral oil base. Contains additives increasing oil film strength, increasing resistance to tool wearing, additives increasing traction and corrosion protection, and to facilitating the process of cleaning items after pressing. It is used for precise process of pressing.

Lubricant C

Cutting-cooling oil produced on the basis of light petroleum fractions and appropriately selected additives. Fast vapor liquid for easy and medium heavy pressing of steel sheets. Surface-treated metal does not require degreasing and the use of other cleaning operations.

Lubricant D

The lubricant produced on the basis of deep-refined mineral oil, soaps of fatty acids containing 10 wt% of natural graphite

Tests carried out on samples cut from a strip of aluminum alloy grade 2024 [8-9] (Fig. 2a), with the chemical composition shown in Table 1. As countersample used as materials of the standard tool steel NC6 (Fig. 2b) and WCL (Fig. 2c). For each study assigned the three new sets of pairs of sample-countersample.

a) b) c)

Fig. 2. Materials for abrasive wear tests
a) Aluminium alloy 2024 strip, b) Counter sample of NC6 steel, c) Counter sample of WCL steel

The abrasion resistance tests were performed by using the T-05 tester (Fig. 3). This tester enabled performing tests in accordance with the methods determined in Standards [10-13]. A similar device for testing the abrasion resistance used authors at [14].

The sample (1) was mounted in a sample holder (4) equipped with a hemispherical insert (3) ensuring the proper contact between the sample and the rotating ring (2). The wearing surface of the sample was perpendicular to the pressing direction. Double lever system input the load L, pressing the sample to the ring with the accuracy of ±1%. The ring rotated with a constant rotational speed.

The wear tests conditions chosen for the current investigations were:

- tested samples - rectangular as-infiltrated specimens 20 x 4 x 1,2 mm,
- counterpart (rotating ring) - φ 49.5 x 8 mm, steel NC6, steel WCL,
- rotational speed – 136 rev./min.,
- load – 60 N,
- test time – 600s.

a) b)

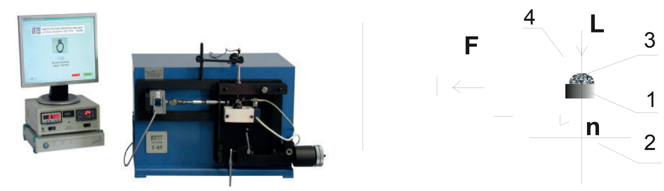

Fig. 3. Block-on-ring T-05 wear tester
a) view of tester, b) schematic of tester

Investigations were performed at a temperature of app. 23°C. The obtained results are presented in diagrams as the dependence of the friction force, depth of wearing out, friction coefficient and the sample mass loss - on the applied lubricant and the counter samples. After finished investigations the microscopic observations of sample surfaces and macroscopic observations of counter samples surfaces (after the wear test) were performed. Observations were performed by means of the optical microscope MULTIZOOM AZ 100 and the digital photo apparatus of the Nikon Company.

TABLE 1

Chemical composition of strip (wt.%)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other	Other total	Al
≤0,5	≤0,5	3,8-4,9	0,3-0,9	1,2-1,8	≤0,1	≤0,25	≤0,15	≤0,05	≤0,15	rest

3. Results and discussion

3.1 Investigation results of the friction force and the depth of wearing out after the abrasive wear

Results of the course friction force and depth of wearing out after abrasive wear, depending on the type of lubricants and countersamples shown in Figure 4-5.

a) b)

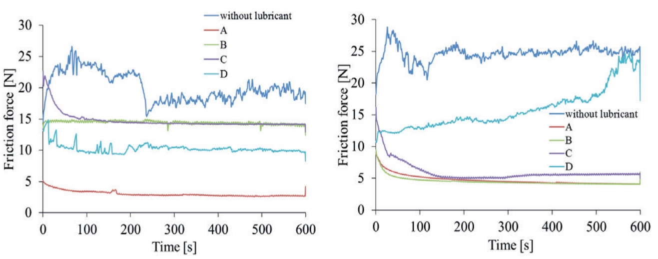

Fig. 4. Abrasion friction force a function of time depending on the types of lubricants
a) countersample NC6, b) countersample WCL

The highest value of friction force using countersample made of steel NC6 was 27N for the test without a lubricant. The course curve of force in this test is non-linear, the values are between 15-27N. Curve C in an initial duration of the test shows a significant decrease in the force of 22N to 15N. After exceeding 100 seconds curve stabilizes at 15N. Curve D is similar, as in the case of the curve in the test without the use of lubricant. However, the curves A and B are the most stable and there are no fluctuations such as in the other tests. Force in the case of the lubricant A is the lowest, and is 3N (Fig. 4a).

The highest value of friction force using countersample of steel WCL was 29N for the test without a lubricant. The values in the force curve in this test are between 19-29N. Curve D shows a significant increase in strength over time (from 10N to 25N). However, the curves A, B and C show a stable course of friction force. Force in the lubricant B is the lowest and is 5N (Fig. 4b).

a) b)

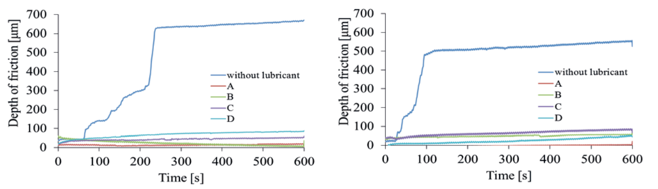

Fig. 5. Abrasion depth of friction as a function of time depending on the types of lubricants
a) countersample NC6, b) countersample WCL

Figure 5a shows the depth of friction over time, depending on the lubricant for countersample NC6. In the case of the test without lubricant curve is rising to achieve 670 μm after the 600 seconds. Curves for lubricants A and B run stable and reaches a value of about 20 μm, for C - 60 μm, while for D - 80 μm.

Figure 5b shows the the depth of abrasion as a function of time depending on the lubricant for WCL Countersample. Curve without the use of lubricant has a similar course as in Figure 4a, but in this case the abrasion depth is 500μm. Curves A, B, C and D show similar values abrasion depth not exceeding 90 microns, with the highest value reached for the lubricant A, while the highest value for the lubricant C.

Results of the average friction force and a maximum depth of wearing off during the frictional wearing of aluminum alloy samples for various kinds of lubricants and countersamples shown in Figure 6.

a) b)

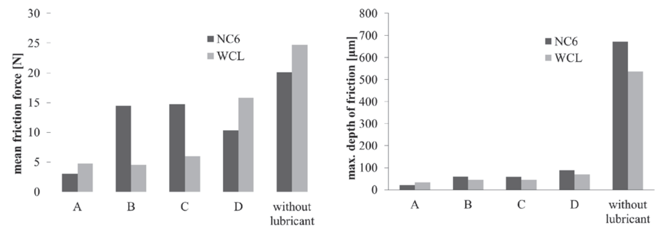

Fig. 6. Measurement results of:
a) mean friction force, b) max depth of friction

Highest average friction force is 20-25N, for samples without the use of a lubricant. Using a lubricant D and countersample of WCL average friction force is comparable with the results of studies using of lubricants B and C and countersample of NC6. The lowest average friction force occurs when testing using a lubricant and countersample of NC6 and lubricant B and countersample of WCL (Fig. 6a).

The minimum depth of wearing off for countersamples NC6 and WCL was observed using a lubricant A. For studies with the use of lubricants B, C, D and countersamples of NC6 and WCL wipe depth values are comparable. The greatest depth of abrasion was observed in the tests without lubricant.

3.2 Investigation results of the mass loss of samples and countersamples after the abrasive wear

Results of mass loss or mass increase samples and countersamples depending on the type of lubricant is shown in Figure 7.

a) b)

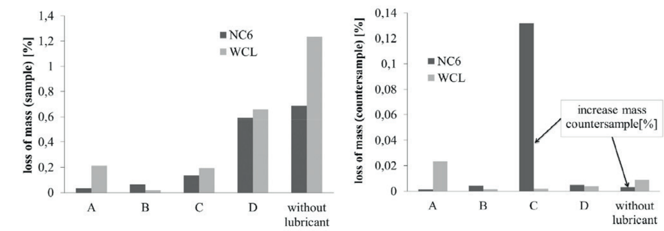

Fig. 7. Measurement results of:
a) the mass loss of samples, b) the mass loss of counter samples

Weight loss 0.7-1.2% is the highest for the samples without the use of lubricant. Using a lubricant D and countersample NC6 weight loss of the sample is comparable with the study without the use of lubricant. The smallest weight loss is close to zero in the case study using lubricant B and countersample of WCL and lubricant A and countersample of NC6 (Fig. 7a).

Weight loss is minimal for countersample of NC6 using a lubricant and for countersample from WCL using lubricants B and C. The characteristic is the increase in mass of NC6 countersample especially for lubricant C and the lack of lubricant. This may indicate sticking the sample material on countersample or a lack of complete removal lubricant and particulates aluminum alloy of the analyzed area after grinding countersample (Fig. 7b).

3.3 Investigation results of the friction coefficient and max. temperature of surface of samples after the abrasive wear

Results of measurement of the friction coefficient and the surface temperature of the samples according to the type of lubricant is shown in Fig. 8.

a) b)

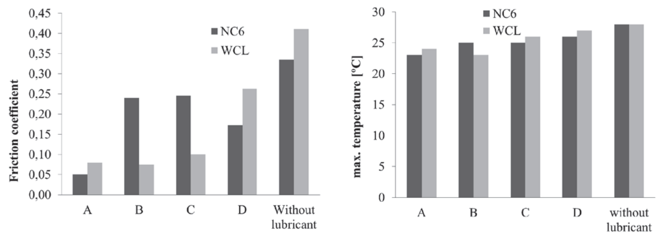

Fig. 8. Measurement results of:
a) friction coefficient, b) temperature of sample surface

The highest coefficient of friction in the range of 0,33-0,40 was recorded in the test without grease. The lowest friction coefficient of 0.05 was obtained for lubricant A and countersample of NC6 (Fig. 8a). Regardless of the type lubricant and the surface temperature of the samples countersample during frictional wear was 23-28°C (Fig. 8b).

3.4 Observation results of the sample surfaces after the abrasive wear.

Results of observation on the surface of aluminum alloy samples after the wear resistance test under different lubrication conditions, using countersamples of different materials is shown in Figure 9.

a) b)

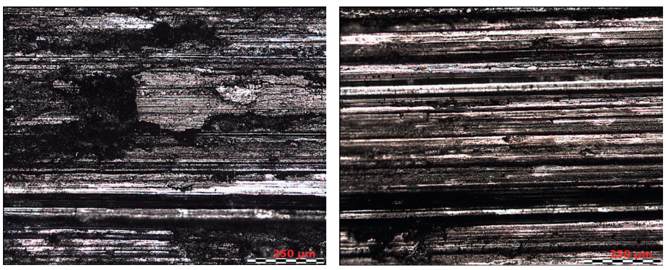

Fig. 9. Microscopic observation of the sample surface after friction test without the use of lubricant
a) countersample NC6, b) countersample WCL

a) b)

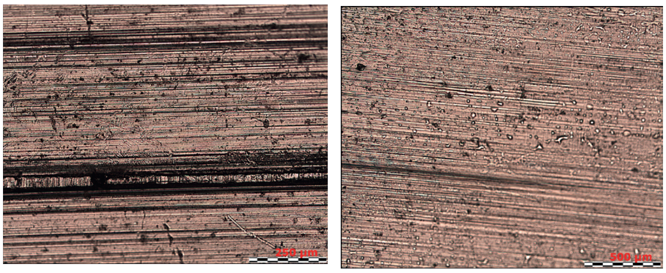

Fig. 10. Microscopic observation of the sample surface after friction test with application of lubricant A
a) countersample NC6, b) countersample WCL

a) b)

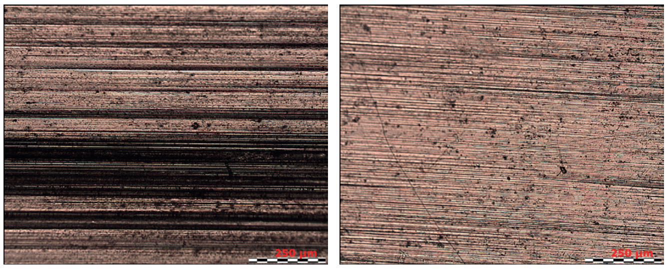

Fig. 11. Microscopic observation of the sample surface after friction test with application of lubricant B
a) countersample NC6, b) countersample WCL

a) b)

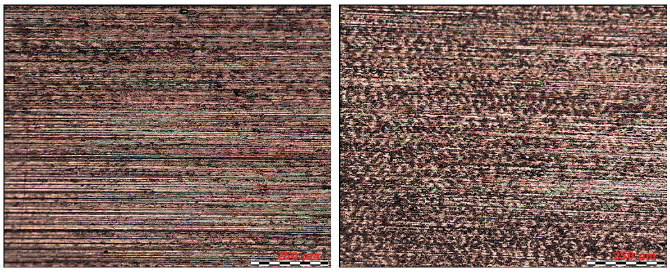

Fig. 12. Microscopic observation of the sample surface after friction test with application of lubricant C
a) countersample NC6, b) countersample WCL

a) b)

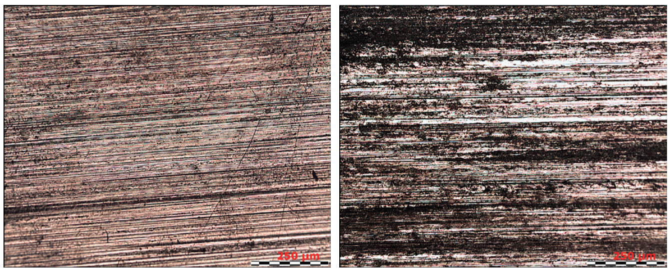

Fig. 13. Microscopic observation of the sample surface after friction test with application of lubricant D
a) countersample NC6, b) countersample WCL

Observations of the surface under tribological contact, help identify mechanisms of wear. On the surface of samples, using countersamples NC6 steel subjected to dry friction can be observed signs of wear by abrasion - mainly microdissection, additionally there is a draw, and scalloping. In this case, the abrasive carbide particles are present in countersample, which project from the surface or are crumbled by tribological contact by increasing the coefficient of friction of the tested materials. In the case of aluminum alloy sheet, great importance also plays adhesive wear consisting of a metallic local tack (adhesion) of the surface friction in the micro-regions of plastic deformation of the surface layer, and particularly the highest peaks of roughness closed to distance of molecular forces, and disruption of their associated subsequent detachment of the metal particles or smearing on the surface friction. Co-occurrence mechanism of the abrasive and adhesive wear can result that the increase of time during abrasive wear will be shown by scuffing. The essence of fatigue damage is local loss of coherence and the associated weight loss. This is due to the cyclicality contact stresses in the surface layers of the co-operating friction elements and thus fatigue. Weight loss after crossing by microregions the border of each material number of cycles and the fatigue limit.

The use of oil A eliminates adhesive wear, which is beneficial for reducing weight loss the tested materials, and the coefficient of friction.

The use of oil A eliminates adhesive wear, however, you can see traces of adhesion.

In case of mentioned lubricants can be concluded that to a large extent, they also eliminate wearing, thus reducing the weight loss of tested sheets and a significant reduction in the coefficient of friction.

The lubricant D reduces the intensity of the adhesive and fatigue mechanism. It reduces the intensity of wear, mainly microcutting. The problem is to deliver lubricant to the friction in a continuous manner. On the surface of the tested materials, using countersamples WCL steel subjected to dry friction can, like the steel countersamples NC6, observed signs of wear by abrasion - mainly microdissection, additionally there is a draw, and scalloping. Also in this case the abrasive particles are present in countersample carbides, which protrude from the surface or are countersample crumbled by tribological contact by increasing the coefficient of friction of the tested materials. For all the plates also plays important adhesive wear, but its intensity is lower than in the case of steel countersample NC6.

4. Conclusions

This paper presents the results of appropriately planned and designed studies of wear resistance of an aluminum alloy sheet 2024 series in different lubrication conditions. Based on the results of research can be provided following conclusions:

1. The lowest average friction force is the lubricant A regardless of the type used countersample, and highest for lubricant D and countersample of WCL.
2. The minimum depth of abrasion occurs after applying lubricant A and regardless of the type used countersample, and highest for lubricant D and countersample of NC6 and lubricant C and countersample of WCL.
3. The lowest coefficient of friction is for lubricant A regardless of countersample, while the largest for lubricant D and countersample of WCL. High values also occur for lubricant B and C and countersample of NC6.
4. The minimum sample mass loss occurs for lubricant A and countersample of NC6, and for lubricant B regardless of countersample, while the maximum for lubricant D regardless of the type used countersample.
5. Minimum loss in mass of countersample is using a lubricant and countersample NC6 and lubricants B and C and countersample of WCL.
6. The characteristic is the large increase in mass of NC6 countersample by using lubricant C, which may indicate sticking the sample material on countersample or a lack of complete removal lubricant and aluminum alloy particles of the analyzed area after abrasion countersample.
7. Irrespective of the type of lubricant and countersample surface temperature of samples during frictional wear was 23-28°C.

Final conclusions:

- For a pair of friction aluminum alloy 2024-steel NC6 the best is lubricant A
- For a pair of friction aluminum alloy 2024-steel WCL the best is lubricant B

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