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TRIBOLOGICAL INVESTIGATION OF THE AUTOMOTIVE GRADE ALUMINIUM ALLOY WITH EPOXY PRIMER COATING

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Abstract: Mechanical surface preparation is a common technique for removing contaminants from surface metal layers. Unlike chemical preparation, it does not require special safety measures, including those for disposal of by-products or toxic materials, thus making it more accessible for different industries. We investigated tribological testing as the experimental method to determine the quality of the coating and the influence of the initial mechanical surface treatment. Samples were made of aluminium alloy EN AW 5083 H111 that was shot blasted with white cast aluminium with resulting surface roughness of Rz=38.908 µm. Samples were further coated with Lankwitzer EvoCor 164 2-component epoxy primer. Tribological test realised on nanotribometer is described and output parameters have been analysed: friction coefficient and penetration depth. Ball-on-flat, dry contact tribological setup was used, with 100 mN normal load, under linear reciprocating motion. Dynamic friction coefficient and penetration depth curves during one tribological test were analysed indicating the moment when the coating exhibited first failure. The test has shown that tribological tests with low loads can be used for quality testing of thin coatings, including the influence of the mechanical surface preparation on the coating adhesion.

Keywords: Aluminium alloy EN AW 5083 H111; Shot blasting; Epoxy primer coating; Micro-tribology; Dynamic friction coefficient.

1. INTRODUCTION

Blasting is common technique used for mechanical cleaning of the surfaces. Process is accomplished by using small sized particles of hardened material onto surface of the substrate. These particles, with high velocities, are hitting material surface, removing contamination such as: corrosion, oxide layers, paint, grease etc. from it. The result is clean, homogeneous, rough surface of the base material which then can be further treated with coating, painting, etching etc. [1] For many different materials, roughness is important parameter which can improve wettability of surfaces. (Kubiak et al., 2011)

Depending on the blasting media, there are different types of blasting technologies. Sand blasting rely on smaller particles with irregular surface morphology, while shots used in shot-blasting technique are spherical with smoother surface. The properties of workpiece (like hardness, morphology and roughness) after abrasive blasting are determined by blasting media used during process. [2]

Usually, after adequately prepared surface, different methods of coatings are applied to base material in order to protect it against degradation. Basdeki & Apostolopoulos in their research mention that, even though it is not a protection method, abrasive particles used in the shot blasting of steel bars could limit corrosion path. [3]

Mechanical surface preparations and coatings are applied in many industries. For example, in aircraft industry, it is important to protect aluminium alloys from the effects of corrosion since it leads to lower values of fatigue resistance and effective loaded area, thus threatening the safety of whole structure. Coating usually consist of epoxy primer and anodic layer, creating double-layer protection. Even protective layer suffers degradation over time which leads to inevitable corrosion of substrate material. [4] Failure of coatings is mainly influenced by the aging of epoxy coating and the factors that determine it are presence of oxygen, corrosive ions and water. [5] Coating, nevertheless, prolongs life cycle of aluminium structure. Zhang et. al demonstrated that protective layers lost their ability after 20 years, where local corrosion occurred, creating corrosion products of Al(OH)3. [4]

One of possible solutions for protection against corrosion is appliance of powder coatings. They can be used on steel and aluminium surfaces and combined with zinc coating. The paint coating of desired color, effect and structure serves to decrease effects of the atmosphere on the zinc. [6]

Other application is in medicine, especially in the dentistry. Implants used in treatment are mostly made of titanium and its alloys. Reason for that is that, aside from its excellent mechanical properties, titanium is great biomaterial and has ability to produce osseointegration with the bone of living organism. [7] Before it can be used as medical implant, titanium must undergo adequate preparation. In order to achieve necessary roughness, sand blasting and grit blasting are used, followed by acid etching. Since blasting particles must have higher value of hardness to produce roughness, alumina particles (Al2O3) are commonly used abrasive. Acid treatment has role in creating micro-roughness within new structure created by abrasive blasting and cannot create meaningful result as standalone process. For osseointegration, osteoblast adhesion and reduction of microorganism colonization, roughness is most important surface parameter. Gil et. al stated in their research that these medical properties are better achieved in implants that were treated with alumina abrasives than implants with same roughness that were not. [8]

Another example of sand blasting in oral medicine is usage of metal-ceramics restorations such as bridges and crowns. These processes are achieved by applying ceramic in semi-liquid state onto metal substructure. Since properties of these two materials differ in many ways, connection between them could create defects which are difficult to repair. To avoid this, first step is to create adequate roughness on metal surface via abrasive blasting. Newly formed unevenness is then filed with semi-liquid ceramics. Size of abrasive particles and parameters used during sandblasting define the quality of the whole process. [9]

Similar thing happens with structural ceramics which have tendency to replace metallic dental prostheses. Kim and Ahn researched influence of particle size of sandblasting abrasives on surface roughness of zirconia. As a ceramic, zirconia has many qualities for application in dental practice. However, there are certain problems like creating bond between it and resin cement. Etching of zirconia surface with hydrofluoric acid is not possible, so mechanical treatment with sandblasting presents logical solution. Better bonding without any damage could be achieved by correctly chosen abrasive blasting parameters, such as: shape and size of abrasive, distance, impact angle, air pressure and duration of process. [10]

2. MATERIALS AND METHODS

Substrate material used in experiment was aluminium alloy EN AW 5083-H111 (AlMg4.5Mn0.7). Two plates, with dimensions of 100 mm in height and width of 100 mm were cut out from aluminium workpiece with thickness of 8 mm. Chemical composition of this aluminium alloy is shown in Table 1.

Table 1. *Chemical composition of EN AW-AlMg4.5Mn0.7 (EN AW-5083)*

Element:	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others (each)	Others (total)
Min:				0.40	4.00	0.05				
Max:	0.40	0.40	0.10	1.00	4.90	0.25	0.25	0.15	0.05	0.15

These plates were then sandblasted with white fused alumina WFA F 040, particle size 80-110 µm under pressure of 3 bar. From the first aluminium plate were then cut out test pieces with dimensions 15x15 mm using water-jet. Measured roughnes of the surface was Rz=38.908 µm. Second aluminium plate was coated with Lankwitzer EvoCor 164-2-component epoxy primer with the thickness of the layer of 80-110 µm and then test pieces with the same dimensions as in previous plate were cut out.

Experimental setup consisted of CSM nanotribometer with Al2O3 ball. Movement of the tool onto test sample surface was linear (reciprocating sliding modul). Friction coefficient and penetration depth were measured. Parameters used for experiment were displayed in Table 2.

Table 2. *Parameters used in experiment*

Amplitude [mm]:	Maximum linear speed [mm/s]:	Normal load [mN]:	Temperature [°C]:	Acquisition rate [hz]:
0.26	2.00	100.00	23.00	10.00

3. RESULTS

Results for friction coefficient obtained from aluminium samples without a coating are shown in Figure 1. Measured values indicate that over time, values of friction coefficient are growing. Same happens with penetration depth, which is displayed in Figure 2, as material becomes more and more fatigued with each passing cycle.

Measured values of friction coefficient on test sample with coating are shown in Figure 3. and penetration depth on this sample is shown in Figure 4.

As results show, values of the penetration depth were rising over time due to material fatigue. The moment when coating layer is penetrated can be seen on diagram as sudden jump in values. This occurs around 1096 seconds after start of experiment.

Friction coefficient value of coated specimen tend to have more balanced value in comparison with the uncoated one, with its dimension progressively growing as coating becomes more and more fatigued.

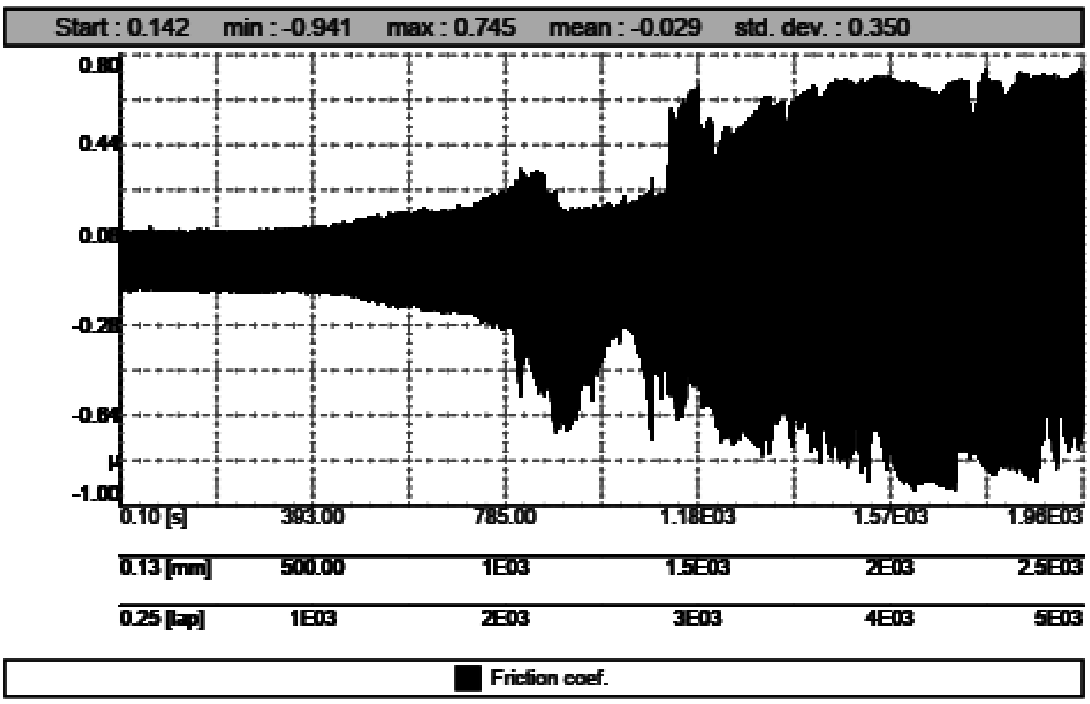

Figure 1. *Friction coeficient measured on uncoated surface of AlMg4.5Mn0.7*

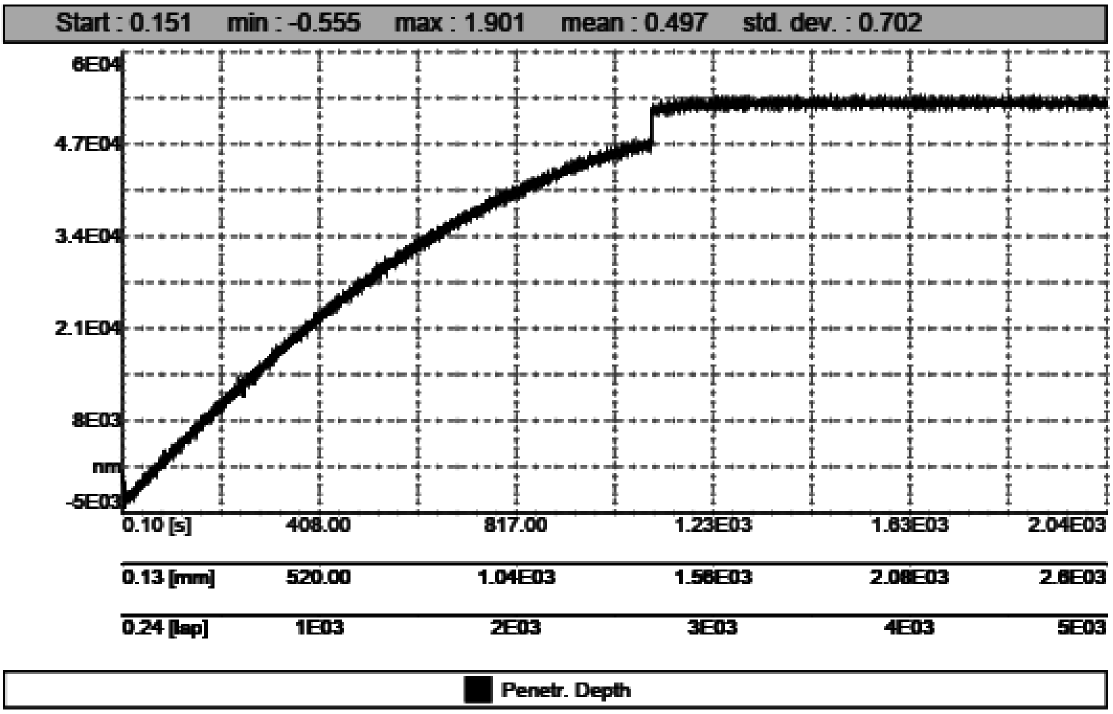

Figure 2. Penetration depth measured on uncoated surface of AlMg4.5Mn0.7

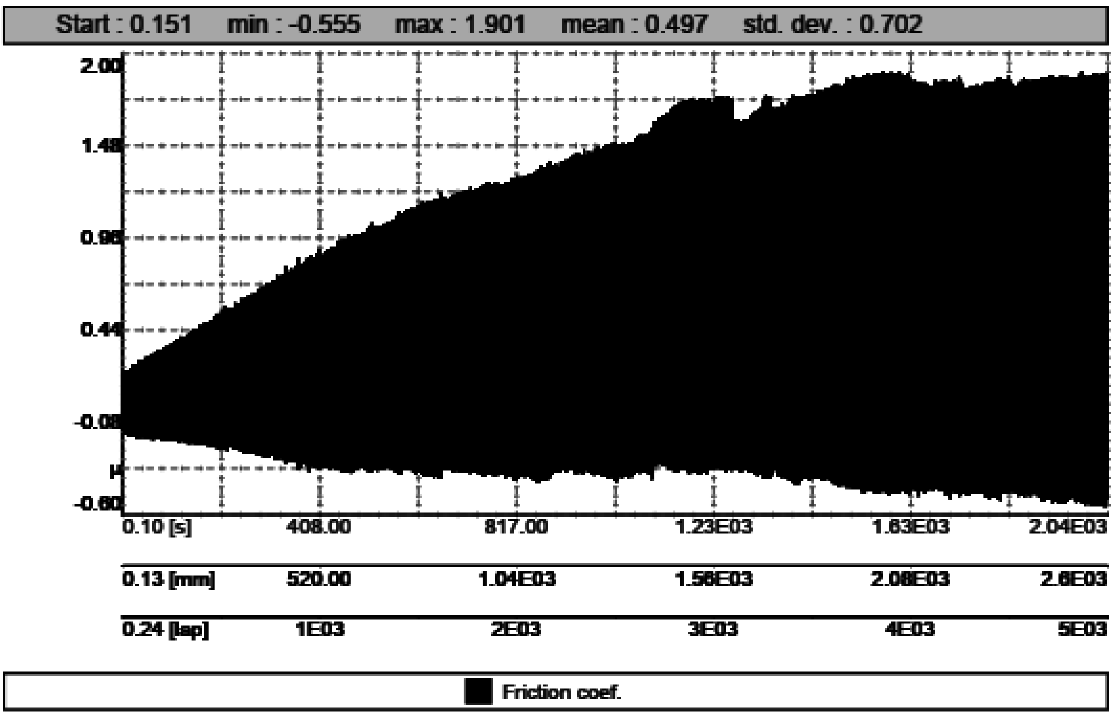

Figure 3. Friction coeficient measured on coated surface of AlMg4.5Mn0.7

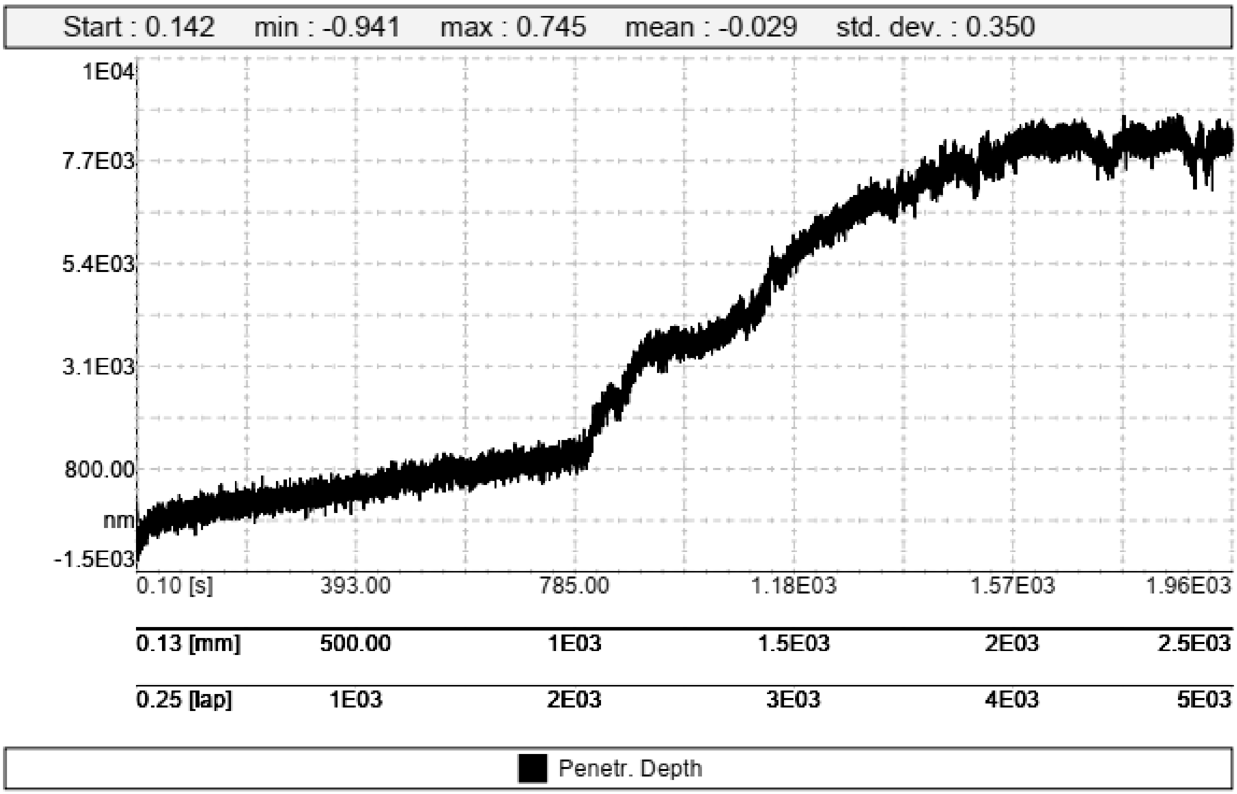

Figure 4. *Penetration depth measured on coated surface of AlMg4.5Mn0.7*

4. DISCUSSION

Epoxy primer coatings are often used in many fields namely, railway and automotive vehicles, aerospace, vessels, tanks etc, because of their corrosion resistance properties. [11] Before an epoxy coating is applied, the substrate surface should be adequately prepared through cleaning, degreasing and chemical or physical modification. Surface preparation and modification are necessary to ensure sufficient adhesion. This is done by creating a specific microstructure on the surface of the substrate and maximizing molecular interaction between the epoxy primer and the substrate surface. Chemical surface modification creates hazardous waste, unlike mechanical methods which are simpler and ecologically cleaner. Mechanical modification works by increasing the surface area of a contact [12]. Increasing the roughness of the substrate increases coating strength [11], which is commonly evaluated by pull-off strength test. Mayer et al (2020) investigated the influence of aluminum substrate surface roughness on polymer-based coating strength. They compared adhesive strengths of epoxy resin coatings applied to a degreased surface and one applied to a surface subjected to abrasive blasting and found that abrasive blasting gave better pull-off test results. They also found that abrasive grain diameter directly affects surface roughness. Increased surface roughness resulted in better adhesion up to a certain point where penetration of the resin became insufficient. Similarly, Mayer et al (2021) investigated the strength of epoxy-based powder filled coatings on aluminum substrate and concluded that abrasive blasting had a major effect on adhesion. Adhesion characteristics of epoxy-coated aluminum substrate were also studied by Sharifi Golru et al (2015). Their approach to increasing surface roughness was using zirconium conversion coating. Zr treated samples showed better pull-off strength results than untreated (degreased) samples and demonstrated cohesive failure, as opposed to adhesive failure that characterized untreated samples. [13]

Aside from conventional ways to asses coating quality, such as scratch test, pull-off test, cross-hatch test etc, nanotribometer results can also give an indication on how resistant the coating is.

5. CONCLUSION

Mechanical preparation and coating have important role in many different fields like: medicine, aerospace industry, railway industry etc. and provide solution for material protection that is cheaper and, in some cases, impossible to achieve with methods which require presence of chemical acids. Thus, it is important to properly understand processes that occur during mechanical surface preparation and protection.

As it is shown, correct appliance of coating on metal surfaces has direct influence on reduction of corrosion advance, making it more resistant to influence of environment. This also prolongs life cycle of protected part, but in order to achieve it, surface needs to be adequately prepared, free of any contamination. Type of abrasive media and parameters used in blasting process (such as grain size of abrasive particles, air pressure, passed time etc.) are of great importance in creation of surface roughness.

Aluminium and its alloys have large application because it is lighter and have better anticorrosion properties in comparison with other metals (steel, for example). However, it is still not immune to the influence of the environment and it is susceptible to degradation of its original properties over time. This creates need for adequate methods of protection in order to extend its usability.

Experimental data indicates that surface of aluminum alloy EN AW-AlMg4.5Mn0.7 coated with epoxy primer has more predictable values in comparison with specimen which was just abrasive treated with white fused alumina. Also, moment when coating was destroyed was detected as rise of penetration depth and maximum values of friction coefficient were achieved after this. Since normal force had small values (100 mN) it took large amount of repeated movements to penetrate coating layer (around 2685 laps).

6. ACKNOWLEGMENT

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ТРИБОЛОШКА ИСПИТИВАЊА АЛУМИНИЈУМСКЕ ЛЕГУРЕ СА ОСНОВНИМ ЕПОКСИ ПРЕМАЗОМ ПРИМЕЊЕНЕ У АУТО-ИНДУСТРИЈИ

Сажетак: Механичка припрема површина је распрострањена технологија која се користи за уклањање контаминената са површинских слојева метала. За разлику од хемијске припреме, не захтева посебне безбедносне мере, попут одлагања нус производа или токсичних материја, што је чини доста приступачнијом у разним индустријама. У овом раду извршена су триболошка испитивања експерименталним методама као подршке код утврђивања квалитета превлаке и утицаја иницијалне механичке припреме површине. Испитивани узорци израђени су од алуминијумске легуре EN AW 5083 H111 која је абразивно очишћена белим стопљеним алуминијумом уз вредност површинске храпавости, после обраде од Rz = 38.908 μm. Потом је извршено наношење премаза у виду Lankwitzer EvoCor 164 2 - епокси прајмера. Триболошка испитивања изведена су на нанотрибометру и извршена је анализа параметара: коефицијент трења и дубина продирања куглице при контакту. Испитивања су вршена контактом куглице о равну површину без подмазивања, нормалне силе од 100 mN са линеарним наизменичним кретањем. Криве динамичког коефицијента трења и дубине продирања током трајања теста су анализиране и на њима је уочен тренутак када долази до пробијања превлаке. Тестом је показано да је могуће вршити проверу квалитета танких превлака са малим оптерећењима, као и утицај механичке припреме на адхезију превлаке.

Кључне речи: Алуминијумска легура EN AW 5083 H111, абразивно чишћење, превлака од епокси прајмера, микро трибологија, динамички коефицијент трења.

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