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Palic, N., Sharma, V., Zivic, F., Mitrovic, S., Grujovic, N.

TRIBOLOGY STUDY OF ALUMINUM-BASED FOAM

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Abstract: *Closed cell metallic foam prepared from ALUHAB technology has been studied using tribological methodology. The main goal of the study was tribological properties of closed cell porous structure made of aluminium alloy. Tribological testing of the porous Al-based alloy were realised under different low loads: 10 mN, 25 mN, 50 mN, 75 mN, and 100 mN using CSM nanotribometer, with linear reciprocating mode. Ball-on-disc contact geometry was used and dynamic friction coefficient was observed. Results revealed that, friction coefficient exhibited large fluctuations in values under different loads, from moderate friction coefficient (0.2 at 100 mN load) up to the very high values (1.4 at 25 mN load). Under very small loads (10 mN) it was hard to get reliable results due to porosity influence and extremely high friction coefficient values were obtained.*

Key words: *Porous structures, Closed – cell Al-based foam, Dynamic Friction coefficient.*

Tribološka ispitivanja pene od aluminijuma. *Metalna pena zatvorene ćelije pripremljena po ALUHAB tehnologiji proučavana je tribološkom metodologijom. Glavni cilj studije bila su tribološka svojstva zatvorene ćelijske porozne strukture izrađene od legure aluminijuma. Tribološka ispitivanja porozne legure na bazi Al izvedena su pod različitim niskim opterećenjima: 10 mN, 25 mN, 50 mN, 75 mN i 100 mN pomoću CSM nanotribometra, sa linearnim načinom recipročnog pomeranja. Korišćena je geometrija kontakta kugličnog diska i primećen je koeficijent dinamičkog trenja. Rezultati su pokazali da koeficijent trenja pokazuje velika kolebanja vrednosti pod različitim opterećenjima, od umerenog koeficijenta trenja (0,2 pri 100 mN opterećenju) do vrlo visokih vrednosti (1,4 pri 25 mN opterećenju). Pod vrlo malim opterećenjima (10 mN) bilo je teško dobiti pouzdane rezultate zbog uticaja poroznosti i dobijene su izuzetno visoke vrednosti koeficijenta trenja.*

Ključne reči: *Porozne strukture, zatvorena pena na bazi Al, koeficijent dinamičkog trenja.*

1. INTRODUCTION

Wear is generally defined as damage to a solid surface which involves loss of material due to relative motion between two surfaces in contact [1]. This motion can be both intentional and unintentional. The frictional force is defined as a tangential force experienced by the resisting interface which is associated with rolling or sliding motion. The nature of relative motion between the bodies and physical mechanism by which material is removed or displaced, categorizes wear into different types such as two body, three body, abrasive or adhesive wear. Quantification of wear is done in terms of volume, mass of material removed or change in linear dimension. Amount of wear is also assessed in terms of wear rate which is defined as rate of material removed per unit of time. According to Archard model of wear quantification constant "K" has important role in determining severity of wear process wherein higher values of K are associated with severe abrasions between surfaces in contact. These values of K find their importance for practical engineering purposes in tribological design [2]. There are some steps which are taken into considerations as described below.

Selection of wear and friction tests. In order to ensure good tribological performance friction and wear testing is done at various stages of the lifecycle of a product.

Selection of approach for testing. Various approaches have been implemented by researchers to assess wear and friction which primarily depends on scale and complexity of elements that are being tested. During the final stage of product abstraction usually, cost-effective laboratory testing is done for better understanding of tribological systems. There are two main situations during which laboratory testing is applied: firstly, when the product is in development stage and is to be selected for the general field of application; Secondly, when a specific application is required which need defined conditions for tribological contact. The selection of parameters is of prime importance for generation of a valid test which can help tribological evaluation of process parameters.

Test parameters. Control parameters and conditions of tribological contact influence wear and friction coefficient. These parameters refer to normal speed, sliding speed, materials of triboelements, temperature [5], contact geometry and environment [3-4], which can be defined by using specific control methods or using same test systems for the whole program.

Interaction with other degradation mechanisms. Chemical reactions and fatigue can also contribute to wear rate. Triboelements exposed to the aqueous environment can experience a positive or negative synergy which increases or reduces wear rate respectively. Similarly, temperature [4] and other stresses such as rolling contact fatigue can also influence degradation mechanism.

Experimental planning and presentation of results. Planning of the tribological testing includes definition

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of controlling mechanical test conditions and sample parameters. Mapping techniques can also be used where two or more factors are changed in a controlled way and results are plotted as individual points or contours. This mapping technique is an efficient way of determining overall behaviour which provides detailed knowledge of wear and friction.

Tribological testing parameters for standard metallic materials are rather well defined, as well as approach to testing under macro loads. However, porous structures which have emerged during the last years imposed certain problems in tribological investigations. The major issue is to provide continuous contact between the surfaces in relative motion where one of the surfaces exhibit porosity, meaning discontinued contact during tribological tests within the zones of the pores. There are some ways to overcome this problem, but in general, more study is needed.

In general, metallic foams have wide range of applications in the aerospace, automotive, and biomedical industries. A large number of researches have performed studies on deformation, fracture, plasticity, dynamic response and energy absorption of cellular foams experimentally and numerically [6]. Open cell aluminium foam has been used for heat transfer enhancement at cryogenic temperature. Such aluminium foam was tested for cryogenic energy storage with a phase change of nitrogen [7]. The properties of Al-based foam are closely related to its pore structure, including pore size, pore distribution and porosity levels [8]. The kinetics of aluminium reaction is manipulated to increase the porosity of geopolymers without adding extra foaming agent, and the impact on porosity development and the characteristics of binding skeleton has been investigated. It is shown that by adjusting the ratio of alkali activators, the oxidation rate of aluminium powder can be regulated, which further impacts the extent of foaming [9].

In this paper, porous aluminium (Al) based alloys have been investigated in relation to application of new structural forms such as open or semi-closed cell foams in different areas, due to their properties such as light weight and ductility. Al-based foams have practical applications as structural materials in many fields (automotive industries, heat transfer systems, anti-vibration systems, and construction industries). Al-based alloys exhibit good corrosion resistance, due to formation of protective layer which prevents further oxidation. However, there are still different issues related to the influence of porous structure, variable temperature, and corrosive environment effects, especially on tribological and mechanical behaviour. Porous structures have significant influence on mechanical properties and further on its tribocorrosive behaviour, in comparison to solid materials. Tribological behaviour of Al-based foams has not been largely investigated. Determination of the wear mechanisms and its development, and friction coefficient behaviour will indicate further improvement in design of these advanced materials. With this aim, this paper investigated tribological properties of closed cell porous structure made of aluminium.

2. MATERIAL AND METHODS

Material used during the testing was closed cell porous structure, as shown in Fig. 1. It was prepared from base material aluminium, with proprietary ALUHAB technology used for the generation and preparation of closed cell porous structure and properties are shown in Table 1. This technology was applied due to its flexibility in terms of uniform, controlled pore size distribution and pore thickness. Minimum cell size that can be achieved using this method was 1 mm.

Density	0.6g/cm3
Cell size	0.5-5.0 mm
Pore size	1.0 mm.
Average cell size	1.0 mm.

Table 1. Physical specifications of ALUHAB based closed cell pore

Tribological testing of the porous Al foam were realised under different low loads: 10 mN, 25 mN, 50 mN, 75 mN, 100 mN. The tests were performed at CSM nanotribometer, with linear reciprocating mode. Purpose of using linear motion is due to its real-world mechanism. It enables calculation of the friction coefficient during the forward and backward movement.

Fig. 1. Front view of the closed cell metallic foam with aluminum as a based material prepared by using ALUHAB Technology

Ball-on-disc contact geometry was used, whereas alumina ball was in sliding contact with Al-based foam and dynamic friction coefficient was observed, as shown in Fig. 2. Tribology tests for sliding contact are distinctly categorized into two distinct types depending on the extent of relative movement.

In the first case, relative movement is sufficiently large (typically greater than 300μm) so that all contact points on at least one of the bodies are out of contact for some of the test period. Contrastingly, the second is a case of fretting, where at least part of the contact area on both samples is always in contact. Ball-on-disc and reciprocating geometries are the most often used tribological test geometries since many applications involve reciprocating motion.

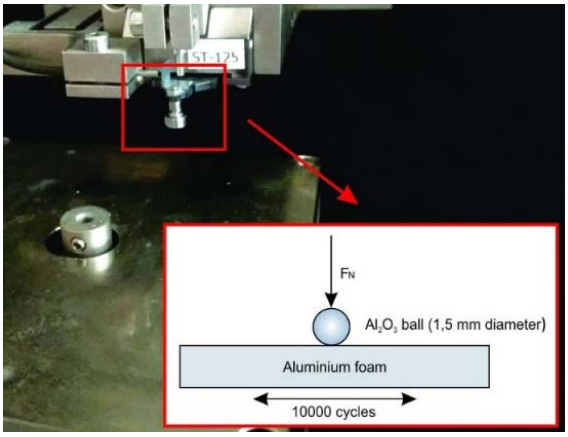

Fig. 2. Represent principle of the nanotribometer, including the module (ball on disc)

3. EXPERIMENTAL PROCEDURES

Porous samples of Al-based alloys were prepared by cutting them from the originally prepared Al-based foam for structural applications. Afterwards the samples were cleaned thoroughly by the flow of dry air. Then the samples were positioned within the two-component epoxy, in order to provide appropriate flat surface for the nanotribological contact. Adequate positioning was important to enable stability of the contact force during the sliding. Table 2. shows the conditions employed during the testing.

Acquisition	Linear Mode
1/2 amplitude	0.25 mm
Max linear speed	2.00 mm/s
Number of cycles	10000 cycles
Acquisition rate	20.0 Hz

Table 2. Tribological Test set up conditions used during the testing.

4. RESULTS AND DISCUSSION

For friction force measurement, most common methods employed are force transducers which are further connected to elastic elements that can sense deflection when force is applied [1].

Frictional coefficients have been identified to be of two types. First is the static friction coefficient which represents friction opposing onset of relative motion. The second type is the kinetic friction coefficient which represents the friction opposing the continuance of relative motion once that motion has started.

Our results showed that porous structure influenced large fluctuations of the friction coefficient. Friction coefficient exhibited large fluctuations in values at different loads, from moderate friction coefficient (0.2 at 100 mN load) up to the very high values (1.4 at 25 mN load). Under very small loads (10 mN) it was hard to get repeatability due to porosity influence and the friction coefficient values in this domain needs further studies since in some repeated tests, under this lowest load extremely high friction coefficient values were obtained.

It can be concluded from Fig. 3, as the normal force of the ball on the surface of the sample increases, the friction coefficient increases. In an area where the normal force approaches 100mN, a large increase in the friction coefficient was observed. This is caused by the high roughness of the aluminium foam surface.

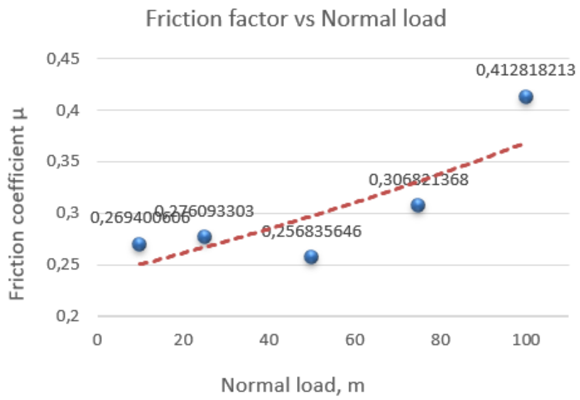

Fig. 3. Friction coefficient versus Normal load during the different loading conditions

Figure 4. shows penetration depth versus sliding distance during the different loading conditions. Based on Fig. 4., it can be concluded that with the increase in normal force, penetration depth started to increase. However, it can be noticed that in the case of load of 75mN, penetration depth is less than for a 50mN load. This phenomenon probably occurred due to the inhomogeneity of the surface of the porous material.

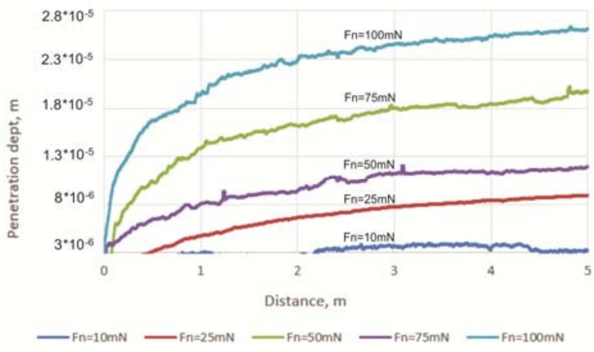

Fig. 4. Penetration depth versus distance during the different loading conditions

This variation in the results is due to the influence of the structure geometry and differences in contact imposed by the differences exhibited by the porous structure properties (high change of surface roughness). Also, topological inhomogeneity has significant influence on the results.

5. CONCLUSIONS

This paper deals with the tribological study of closed-cell aluminium-based foam using nanotribometer. Results indicated that due to zig- zag arrangement of pores it is hard to establish the reliable setup for experiments, especially under very low loads. Different low loads were applied, (10 mN, 25 mN, 50 mN, 75 mN, 100 mN) and rather large fluctuations of the dynamic friction coefficient were exhibited.

Porosity (size and shape of voids, as well as their distribution) greatly influenced the results due to introduction of non-uniform surface properties, from both aspects of contact area and roughness changes over the surface. Topological inhomogeneity caused deviation in results. Further testing of contact conditions and influences, are needed especially for very low loads (below 10 mN).

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Authors: **Nikola Palic, Varun Sharma, Fatima Zivic, Slobodan Mitrovic, Nenad Grujovic**, University of Kragujevac, Faculty of Engineering, Kragujevac, Sestre Janjic 6, 34000 Kragujevac, Serbia
Phone.: +381 34 335 990
E-mail: nikpa2112@gmail.com; varun.eu@gmail.com; zivic@kg.ac.rs; boban@kg.ac.rs; gruja@kg.ac.rs

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