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Wear behaviour of composite materials based on 2024 Al-alloy reinforced with δ alumina fibres

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Materials

ABSTRACT

Purpose: Wear improvement of aluminum matrix composite materials reinforced with alumina fibres, was investigated. The effects of the applied pressure and T6 heat treatment on wear resistance were determined.
Design/methodology/approach: Wear tests were carried out on pin-on disc device at constant sliding velocity and under three pressures, which in relation to diameter of specimens corresponds to pressures of 0.8 MPa, 1.2 MPa and 1.5 MPa. To produce composite materials porous performs were prepared. They are characterized by the suitable permeability and good strength required to resist stresses arising during squeeze casting process. Performs exhibited semi-oriented arrangement of fibres and open porosity enabled producing of composite materials 10% (in vol.%) of Al_2O_3 fibres (Saffil).
Findings: In comparison with T6 heat treated monolithic 2024 aluminium alloy composites revealed slightly better resistance under lower pressure. Probably, during wear process produced hard debris containing fragments of alumina fibres are transferred between surfaces and strongly abrade specimens. Under smaller pressures wear process proceeded slowly and mechanically mixed layer MML was formed.
Research limitations/implications: Reinforcing of 2024 aluminium alloy could be inefficient for wear purposes. Remelting and casting of wrought alloy could deteriorate its properties. Interdendrite porosities and coarsening of grains even after squeeze casting process were observed.
Practical implications: Aluminum casting alloys can be locally reinforced to improve hardness and wear resistance under small pressures.
Originality/value: Investigations are valuable for persons, what are interested in aluminum cast composite materials reinforced with ceramic fibre performs.
Keywords: Aluminium matrix; Alumina fibre; Composites; Wear resistance

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1. Introduction

Nowadays the most promising materials for advanced and novel industrial requirements include composite materials based on light weight alloy matrix reinforced with ceramic particles or fibers. Usually preheated liquid alloy infiltrates a porous preform, which exhibits skeleton structure and planned open porosity. The reinforcement are typically made on the basis of ceramic or carbon based materials, which could be produced in one step as a porous structure from separate components which are joined with inorganic binders. Open porosity is the main factor influencing on the route of manufacturing process and finally composite material properties. The last attempts concern manufacturing of materials using firing of some components and forming channels through which, in the next stage, liquid metal can flow [1-4]. In the case of fibre preform skeleton structure should exhibit possibly small amount of barriers formed usually from silica or phosphor binder [5-6].

In the most frequently applied squeeze casting method quickly flowing metal could be hindered by reinforcement, what can generate large forces, which can deform the ceramic preform. Thus, properties of preform and suitable parameters for composite manufacturing affect microstructure, reduce defects, improve interface between the reinforcement and the matrix and finally enhance physical and chemical properties.

In many applications composite materials should demonstrate high strength and good wear resistance in wide temperature range and at different conditions [7-10]. Dry friction under changing pressure is frequently observed in practical application, so reinforcing of the light weight aluminium matrix with hard ceramic fibres could be useful and beneficial. In this study typical 2024 aluminium alloy was reinforced with alumina fibres using standard squeeze casting method. Considerable attention was paid to determine the wear mechanism and the understanding of observed reinforcing effect.

2. Experimental procedure

For producing of composite materials the porous ceramic preforms were made of „Saffil" ceramic fibres. The chemical composition and physical properties are listed in Table 1. Fibres contain ca. 3-4% of silica, which prevents aluminium oxide grain growth at high temperature as well as improves the resistance of the fibres to chemical corrosion.

I order to produce the performs wet forming process, incorporating a few stages, was applied. First, a water solution of silica binder with an addition of starch was prepared. Then, after adding the respective amount of the fibres, the mixture was mixed and dried out. Next by squeezing the perform was given the assumed form and porosity. Finally the perform was dried and fired at 950°C. The performs exhibit a skeleton structure, with a disorderly arranged fibres in the horizontal plane whereas the fibres are partially ordered in the vertical planes.

Table 1.
Chemical composition and properties of Saffil alumina short fibres

Composition	
Al_2O_3 - δ	96 - 97%
SiO_2	3 - 4 %
shot content	negligible
Physical properties	
melting point	> 2000 °C
maximum operation	1600 °C
tensile strength	1500 MPa
Young's modulus	300 GPa
mean diameter	3.5µm
mean length	200µm
density	3.3g/cm^3

To infiltrate and produce composite materials squeeze casting process was used. The main parameters affecting the composite materials quality include the temperatures of the die, the perform and the matrix alloy. The infiltration pressure which can reduce porosities and improve interface between the matrix and the reinforcement amounted 90 MPa and was kept as long as completely solidification was reached. The composites were produced on the base of 2024 aluminium alloy (Table 2), which could be effectively heat-treated. Most frequently, this alloy is used in production of typically, fairly complex, strongly loaded machine parts.

Table 2.
Chemical composition of 2024 alloys in weight %

Alloy	Cu	Mg	Mn	Fe	Al
2024	3.80 - 4.90	1.20 - 1.80	0.30 - 0.90	<= 0.50	balance

From the composite material cylindrical specimens were cut out and turned to diameter of 8 mm. Friction surfaces of the counterpart and composite materials were polished with abrasive paper 800 and cleaned with acetone. The specimens were pressed against tool steel CT70 counterpart with forces corresponding to pressures of 0.8, 1.2 and 1.5MPa. The tests were performed on a pin-on-disc device with a horizontal rotating disc at constant linear velocity of 1m/s. After the friction distance of 1000 m the specimens were weighed with accuracy of 1 mg.

3. Discussion of test results

3.1. Heat treatment T6 and hardness HB

Limit line solubility of Cu in Al extends between the maximum solubility of 5.7% Cu at eutectic temperature and 0.1% at ambient temperature. Because first observation of saturated specimens evidenced presence of intermetallic particles $CuAl_2$ (Θ), the standard temperature was increased to 513°C. In the case of composite materials, during manufacturing and reinforcing, numerous dislocations contribute to vacancies annihilation and creation of GP 2 (Θ'') zones. Thus, increasing rate of aging process caused by enhancing kinetics of Θ' precipitations effect on earlier occurrence of hardness peak [11]. The increase of hardness can also be achieved by natural aging. In the work [12] after about 170h of natural aging the comparable hardness was obtained as after artificial aging for 10-20h at 120-160°C. In [13] natural aging of Al-2024/TiC composite materials resulted in better mechanical properties of the composite than of material aged in artificial conditions. This was explained by partial dissolution of GP zones during artificial aging and coalescence of micro voids. At higher reinforcement contents stronger lattice deformation and restrained diffusion of larger Cu atoms may also delay formation of the transitional phase and reduce the dynamics of aging. In presented study the highest increase was observed after 15h of age hardening both for unreinforced alloy and composite, see Fig. 1. Reinforcing with 10% of Saffil fibres resulted in 20-30% hardness increase whereas subsequent heat treatment enhance it by further 10-20% to maximum value of 160HB.

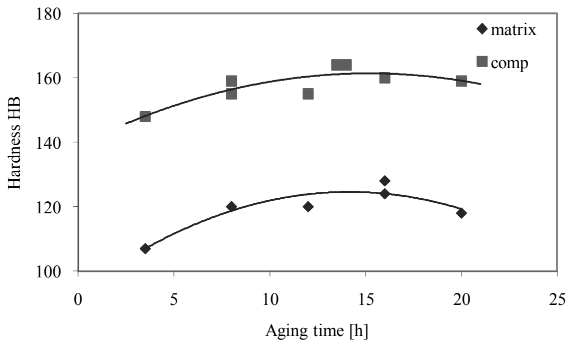

Fig. 1. Hardness HB of 2024 alloy and 2024-10% Saffil composite material vs. age hardening time

3.2. Wear resistance under different pressures

Examination of wear rate were performed on as cast specimens and after T6 heat treatment. Aluminium matrix reinforced with 10% of fibres revealed better resistance only under higher pressures (see Fig. 2). When composite specimen was pressed against counterpart with the lowest pressure of 0.8 MPa its mass loss was about 10% larger than of unreinforced 2024 alloy.

After T6 heat treatment resistance of all specimens significantly increased. Mass loss was almost three times lower and effect of reinforcement content changed. In this case, under lower pressure of 0.8 MPa wear rate of unreinforced 2024 alloy was higher than the composite material (see Fig. 3). Unfortunately, with increase of pressure to 1.2 MPa, the tendency was reversed and the composite material exhibited slightly worse wear resistance. Similar results on composite materials Al-4.3% Cu-20% of Saffil fibres were obtained by Perrin [14]. According to [14] only under low 6N pressure composite materials were more resistant, but when pressure increased to 40 N mass loss was 6 times larger.

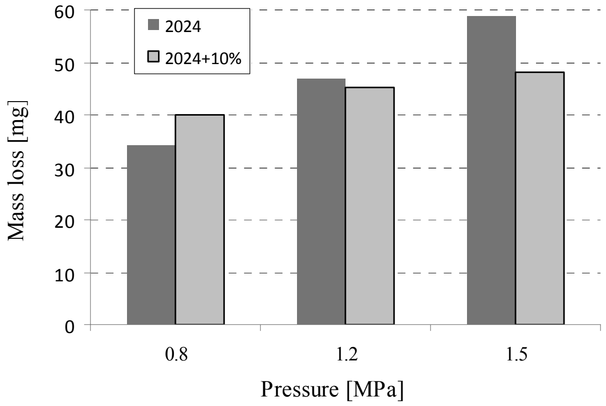

Fig. 2. Effect of pressure on mass loss of as cast unreinforced 2024 alloy and composite materials reinforced with 10% of Al_2O_3 fibres

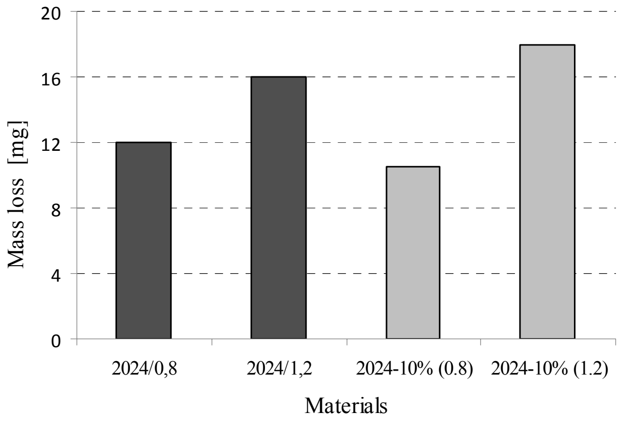

Fig. 3. Mass loss of cast unreinforced 2024 alloy T6 and composite materials reinforced with 10% Al_2O_3 fibres T6

Average value of friction coefficient determined for 2024 alloy and composite material were 0.37and 0.45 respectively. Probably, during sliding the broken fibres are transferred between wear couple and as debris enlarge friction force, thus effecting on the friction coefficient.

3.3. Microscopic study of wear surface

Friction surfaces and surface layer microstructure were examined to determine wear mechanism. It could be found that friction surface of unreinforced 2024 alloy specimen is relatively smooth and plain, (see Fig. 4a).

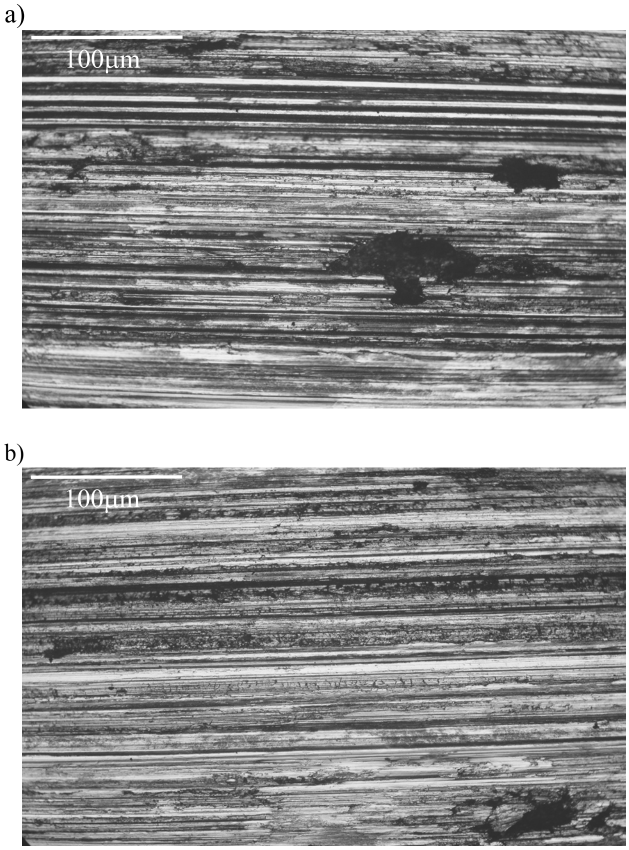

Fig. 4. Friction surface of as cast unreinforced 2024 alloy (a) and of composite material 2024+10 vol. % of Saffil (b) after test under pressure of 1.5 MPa

Formed micro-contacts were sheared and deformed with subsequent grooving. Under locally concentrated stresses some microstructure defects cracks of surface can develop. Next they were usually transformed into pits or larger pockets filled with wear products. In relation to composite materials number of pits was similar irrespectively on the pressure used in wear test. With wear progress, previously formed pits could be covered by plastically deformed material. Next such thin films were broken and with oxides produced debris like small flakes.

Microstructure of surface layer of unreinforced 2024 alloy after hardening by heat treatment T6 is characterized by better resistance to deformation and erosion comparing to the not treated alloy. Under low pressure of 0.8 MPa grains adjacent to the surface were slightly deformed, (see Fig. 5a). Probably they were gradually abraded and oxidized before plastic flow occurred. With increase of pressure to 1.2 MPa deformation zone was larger. In some areas, especially at the bottom of the grooves, pockets with mixing and rubbing wear products were formed. Under pressure they were deepened and wedged until at some point flowed matrix covered and close them, (see arrow in Fig. 5b). Finally the phenomenas of cracking and peeling can be observed.

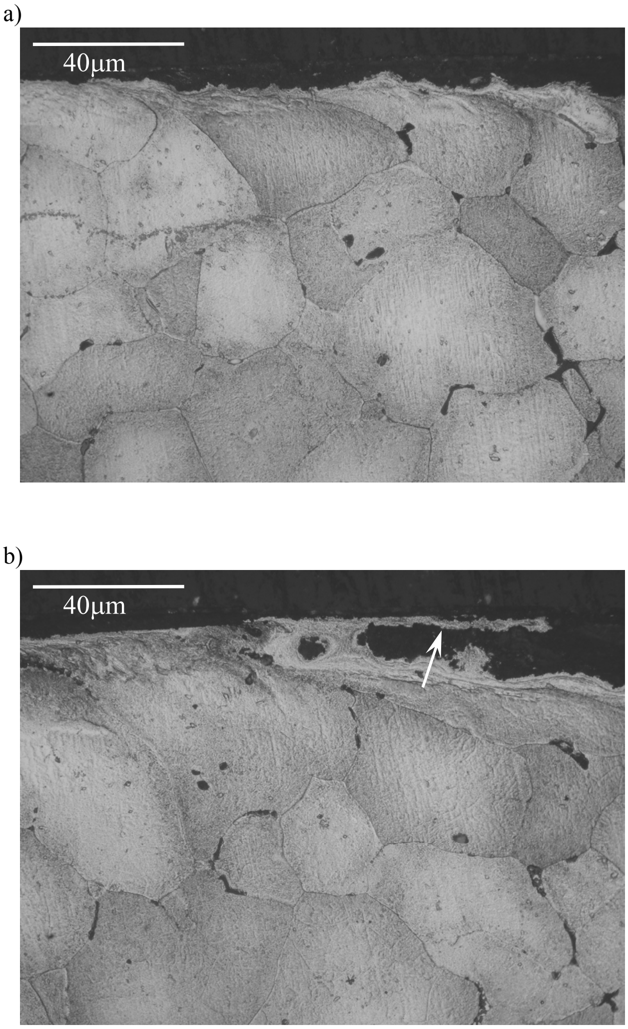

Fig. 5. Microstructure of the surface layer of T6 heat treated unreinforced 2024 alloy after wear test under 0.8 MPa (a) and 1.2 MPa pressures (b)

In the case of composite materials observations focused on the examination of the fibres behaviour, the degree of cracking, deformation of the matrix restrained by the fibres and determination of the dominant wear mechanism. Under low pressure of 0.8 MPa as cast composite materials was weared relatively quickly. Only layer of few microns with fragmented fibres was formed, (see Fig. 6a). With increase of pressure to 1.2 MPa this layer thickened to 30-40µm. Though deformation of the matrix was restrained by the fibres they cracked and their small segments were transported and mixed with the matrix (Fig. 7). Thus mechanically mixed layer (MML) was formed and usually this layer lost its connection with the base material. Next a crack and exfoliation followed by abrupt rise of wear developed.

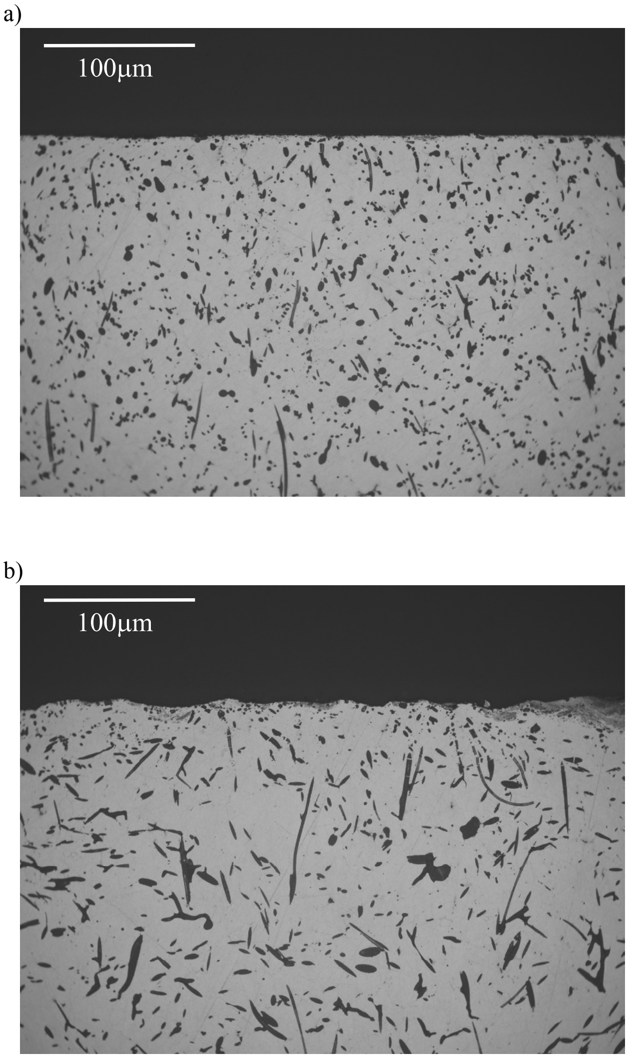

Fig. 6. The surface layer of as cast composite material 2024+10 vol. % of Saffil obtained after tests under 0.8 MPa (a) and 1.2 MPa pressures (b)

Surface layer of T6 heat treated composite material is characterized by higher hardness and better wear resistance than of unreinforced alloy was formed in similar manner. Zone with fragmented fibres and mechanically mixed layer MML, (see Fig. 8) was developed with test progress. Under lower 0.8 MPa pressure, thickness of MML was larger of ca. 30-40 μm. With increase of pressure, probably surface was abraded before fibre cracking occured and debris rubbing followed. In slightly plastically deformed layer fibres were in good condition though they cannot restrain wear of composite material. Presumably, fibres increased number of hard particles between wear pair and contributed both to the reinforcing and weakening effect.

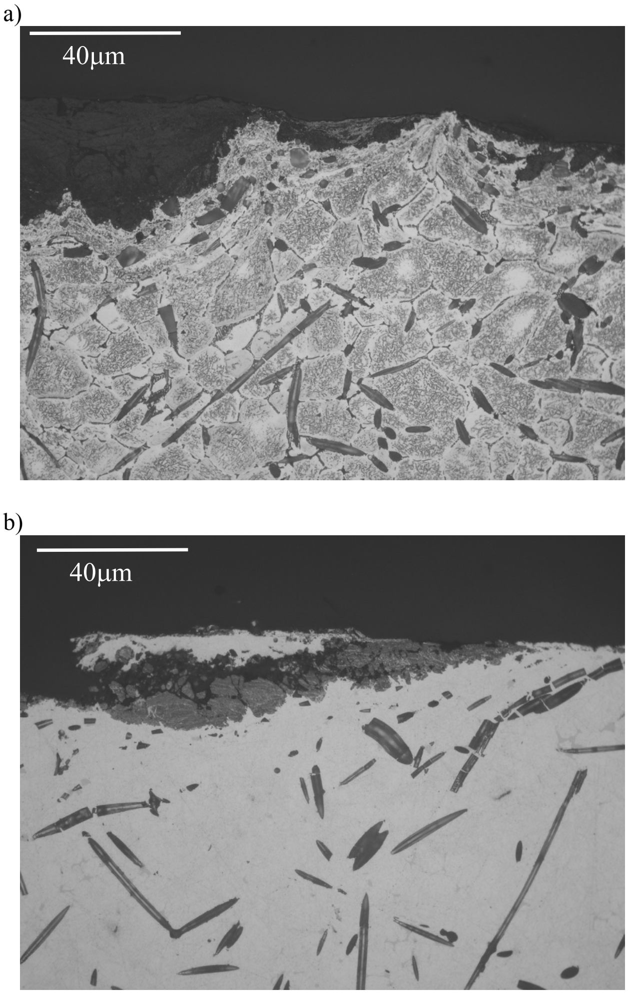

Fig. 7. Deformation of surface layer of as cast composite obtained after tests under pressures of 1.2 MPa (a) and 1.5 MPa (b)

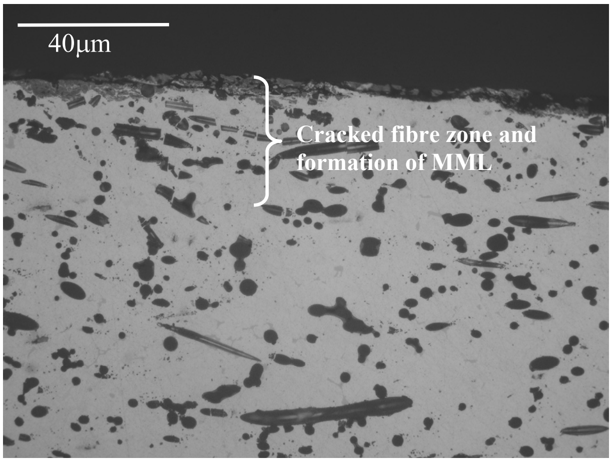

Fig. 8. The surface layer of 2024-10% Saffil composit material obtained after tests under pressure of 1.2 MPa, after T6

4. Conclusions

Produced by squeeze casting method 2024 based composite materials reinforced with Al_2O_3 Saffil fibres were subjected to dry wear examinations. On the base of results of wear tests under different pressures and microscopic observations of surface layer the following conclusion were made:

1. Reinforcing of 2024 aluminium alloy with 10 vol. % of Al_2O_3 Saffil fibres improved wear resistance of as cast composites only under high pressures of 1.2 and 1.5 MPa.
2. After T6 heat treatment hardness of composite materials increased 10-20% to its maximum value of 160HB.
3. Simultaneously wear rate of composite materials considerably (alomst three times) decreased. Effect of the pressure was also changed. Only under lower 0.8MPa pressure composite materials exhibited better resistance than unreinforced alloy.
4. Wear process of unreinforced as cast 2024 alloy proceeded with plastic deformation of surface grains especially under higher pressure (Fig. 9).
5. Surface of as cast composite materials under lower pressure was abraded. With increase of pressure mechanically mixed layer MML was created protecting composite material and reducing wear rate.
6. During dry sliding wear of T6 heat treated composite materials MML was formed under the relatively low pressures.

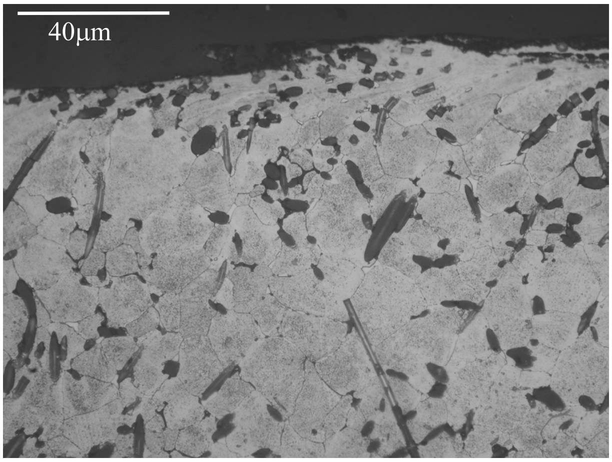

Fig. 9. Etched microstructure of surface layer with visible deformed grains in 2024-10% Saffil composite material obtained after tests under pressure of 1.2 MPa, after T6

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