Archives of Materials Science and Engineering

Volume 74
Issue 2
August 2015
Pages 77-84

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Influence of the milling time and MWCNT content on the wear properties of the AlMg1SiCu/MWCNT nanocomposites

L.A. Dobrzański*, M. Macek, B. Tomiczek, W. Pakieła, M. Kremzer
Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding e-mail address: leszek.dobrzanski@polsl.pl

ABSTRACT

Purpose: In the present article, the wear behaviour of aluminium alloy matrix nanocomposites containing various amounts of carbon nanotubes (0, 2 and 5 vol.%) fabricated using powder metallurgy route has been investigated.

Design/methodology/approach: In order to provide the uniform dispersion of the reinforcement particles in the aluminium matrix, in the study, mechanical milling has been used. Through a repeated process of cold welding, fracturing, and re-welding during the mechanical milling, carbon nanotubes are being well embedded between the deformed particles. The tribological test has been performed using a ball-on-plate wear tester.

Findings: The microhardness testing has found that addition of carbon nanotubes increases nanocomposite hardness. The results of wear behaviour has showed the influence of the nanocomposite powders preparation conditions on the tribological properties of the final material.

Practical implications: Nanocomposites reinforced with carbon nanotubes were prepared using powder metallurgy method what shows the practical implications of the manufacturing of nanocomposites.

Originality/value: The results show that because of the simplicity and availability the technology of manufacturing can find the practical application in the production of new light metal matrix nanocomposites. It has been found out that carbon nanotubes, used as reinforcing phase have the influence on the properties of metal matrix composites.

Keywords: Nanocomposites; Powder metallurgy; Mechanical milling; Carbon nanotubes; Aluminium alloys

Reference to this paper should be given in the following way:

L.A. Dobrzański, M. Macek, B. Tomiczek, W. Pakieła, M. Kremzer, Influence of the milling time and MWCNT content on the wear properties of the AlMg1SiCu/MWCNT nanocomposites, Archives of Materials Science and Engineering 74/2 (2015) 77-84.

PROPERTIES

1. Introduction

Metal Matrix Composites (MMCs) have become an important class of materials for structural, wear, thermal and electrical applications. Because of their superior strength-to-weight and strength-to-cost ratios when compared to equivalent commercial alloys.

The metal matrix composite properties depend on the matrix metal, reinforcement material, reinforcement particle size and composite fabrication method.

The aluminium based matrix composites have the potential to offer desirable properties, including strength, high specific stiffness and excellent wear resistance, that make them attractive for numerous applications in aerospace, automotive and military industries. To increase the mechanical and wear properties of the aluminium composites the nano-sized reinforcements materials have been applied.

Carbon nanotubes, which are graphene sheets rolled into a cylinder are characterised by extremely high mechanical, thermal and electric properties like no other known engineering materials. Their very high strength (~63 GPa), high stiffness (~970 GPa) and very low density (~1.4 g/cm^3) make them ideal candidates as the reinforcing phase in production of light metal matrix nanocomposites with improved properties [1-3].

The main problem in the composite nanomaterials reinforced with carbon nanotubes is the creation of the agglomerates and the irregularity of their distribution in the material matrix because of the strong van der Waal's force between them [4-5].

They are a few method used in that kind of nano-materials manufacturing process such as casting, spraying or powder metallurgy [6-9]. From all of them high energy mechanical milling became one of the most popular ones because of the simplicity in reinforcing phase incorporation into the metal matrix [2,4,5].

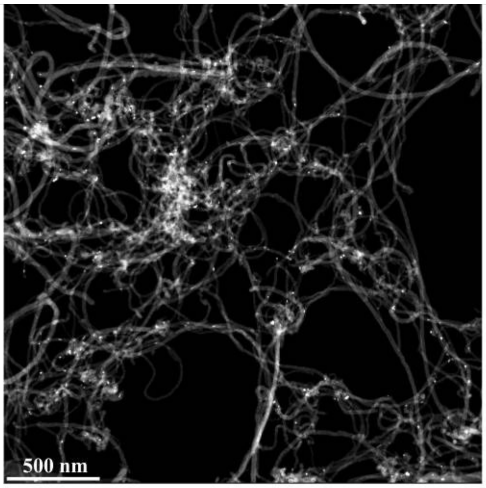
In the present work, the wear behaviour of aluminium alloy matrix nanocomposites with various amounts of carbon nanotubes fabricated using powder metallurgy route has been investigated.

2. Experimental procedure

Powder metallurgy technique was used in the MWCNT-reinforced AlMg1SiCu nanocomposites fabrication. The dispersion of MWCNT in the aluminium alloy powder using high-energy mechanical milling process. The MWCNT (20-50 nm in diameter and >5 µm in length, Cheap Tube, USA) (Fig. 1) and the AlMg1SiCu alloy powder (the average particle size < 63 µm, ECKA Company, Germany), with the addition of the 1 wt.% of polyamide wax as a process control agent, have been mixed using a planetary ball milling. The chemical composition of the AlMg1SiCu alloy has been summarised in Table 1. Set of the composite powders containing 0, 2 and 5 vol.% of MWCNT has been prepared. Each composite powders have been milled for 5 and 10 h. The milling speed has equalled 200 rpm. Ball to powder mass ratio (BPR) has been 20:1. The powders have been placed in the steel jar with thirty milling balls, with the diameter of 20 mm. To avoid overheating after every 0.5 h of milling 0.5 h of cooling has been applied.

The next step in the nanocomposite preparation has been the plastic consolidation of the obtained composite powders. The powders were consolidated by hot extrusion at 480°C.

a)



b)

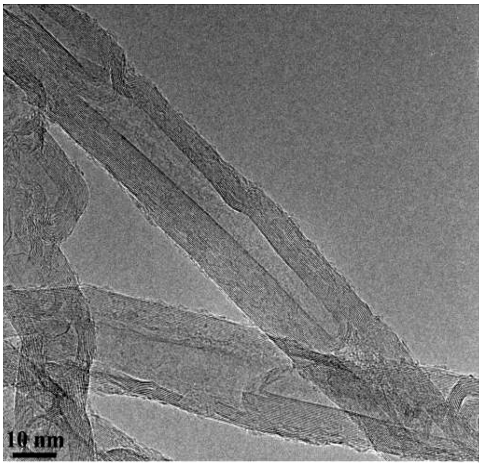


Fig. 1. Morphology of the as-received multi-walled carbon nanotubes: a) TEM, b) HRTEM

Table 1.
The chemical composition of the AlMg1SiCu alloy

Element	Mg	Si	Cr	Cu	Fe	Mn	Zn	Ti	Al
wt.%	0.95	0.6	0.26	0.22	0.47	0.11	0.015	0.006	Balance

The characterization of carbon nanotubes has been performed by electron microscopy (TEM) and high-resolution transmission electron microscopy (HRTEM) Titan 80-300 FEI.

Mechanical properties of the obtained nanocomposites have been evaluated by microhardness and wear test. The microhardness has been measured using Vickers method under the 0,981 N load. On each sample, ten measurements have been done. The wear behaviour has been performed by ball-on-plate test under the load of 5 N for 25 m distance using TRIBOMETER CSM Instrument. Schame of the device has been presented in ref. [10].

Microstructural characterization of AlMg1SiCu/MWCNT nanocomposites surfaces after wear tests with various MWCNT's concentration after different milling time has been performed by scanning electron microscope Zeiss SEM SUPRA 35.

3. Results

Mechanical milling, which has been used in the study, produces the uniform dispersion of the reinforcement particles in the matrix through a repeated process of cold welding, fracturing, and rewelding, giving increase to the reinforcement particles being entirely embedded in the matrix particles [11].

The wear tracks, worn surface microstructure, friction coefficient and wear rate of unreinforced aluminium alloy and AlMg1SiCu/MWCNT nanocomposites with varying amount of the reinforcing phase and after different milling time have been summarized in Figs 2-7.

Figures 2a-7a reveals an optical image of the wear track of the specimens after sliding wear without and with 2 and 5 vol.%. MWCNT respectively. The wear tracks of unreinforced samples have much more irregular shape and dimensions, in comparison to samples with an addition of MWCNTs. It is also easily visible that the width of the wear track is much more broader in the middle.

SEM micrographs of worn surfaces (Figs 2b-7b) clearly demonstrate the presence of longitudinal grooves in all samples. In addition, by comparing the worn surfaces, it is obvious that the scratches, craters, and delamination of AlMg1SiCu/MWCNT nanocomposites are less than that of the unreinforced alloy. For raw aluminium alloy, the wear mechanism is dominated by micro ploughing and delamination.

The wear volume gradually decreases as an increase of the MWCNT volume up to 5 vol.%.

The worn surface of the samples with 5 vol.% of MWCNT are smoother and along the sliding direction and almost no dimples are observed in their fracture surface. This is due to greater hardness and strength imparted to the material by addition of MWCNT.

However, the material without MWCNT content exhibits rough, worn scar because debris is readily separated from the surface possibly due to the present of pores (Figs 2b, 3b) have shown severe subsurface fracturing and deep pits. On the Figs 2b and 3b a series of craters and cracks have been observed on the surface of the samples. In that case, both worn sample's surfaces are similar. The deepest depth and broadest width have been observed on the worn surface of the sample without MWCNT content.

Entrapped debris between delaminated surfaces has been noticed at high magnification on worn surfaces of unreinforced AlMg1SiCu alloy while there less wear debris on the worn surfaces of nanocomposite as shown in Fig. 7b. That debris is from the heavily milled consolidated powders which have been detached under the load during the wear test. Also, weak bonding between MWCNT and AlMg1SiCu particle could be another reason for crack initiation and propagation after longer distance of wear test.

To identify wear resistance of the obtained composites, the friction coefficient has been examined during the "ball-on-plate" wear test. Figures 2c-7c show the friction coefficient for unreinforced aluminium alloy and AlMg1SiCu/MWCNT nano-composites. Friction coefficient is a function of the sliding distance for a normal load of 5 N.

The results have revealed that the friction coefficient for composites reinforced with MWCNT is slightly lower, and also has smaller fluctuation as compared to the unreinforced alloy. In the begging, up to 5 m, for all composite, the friction coefficient decreased slightly. The initial increase may be caused by the increasing friction force which is needed to overcome contact between tested surfaces. The decrease in the friction coefficient may be due to the formation of the mechanically missed layer on the surface.

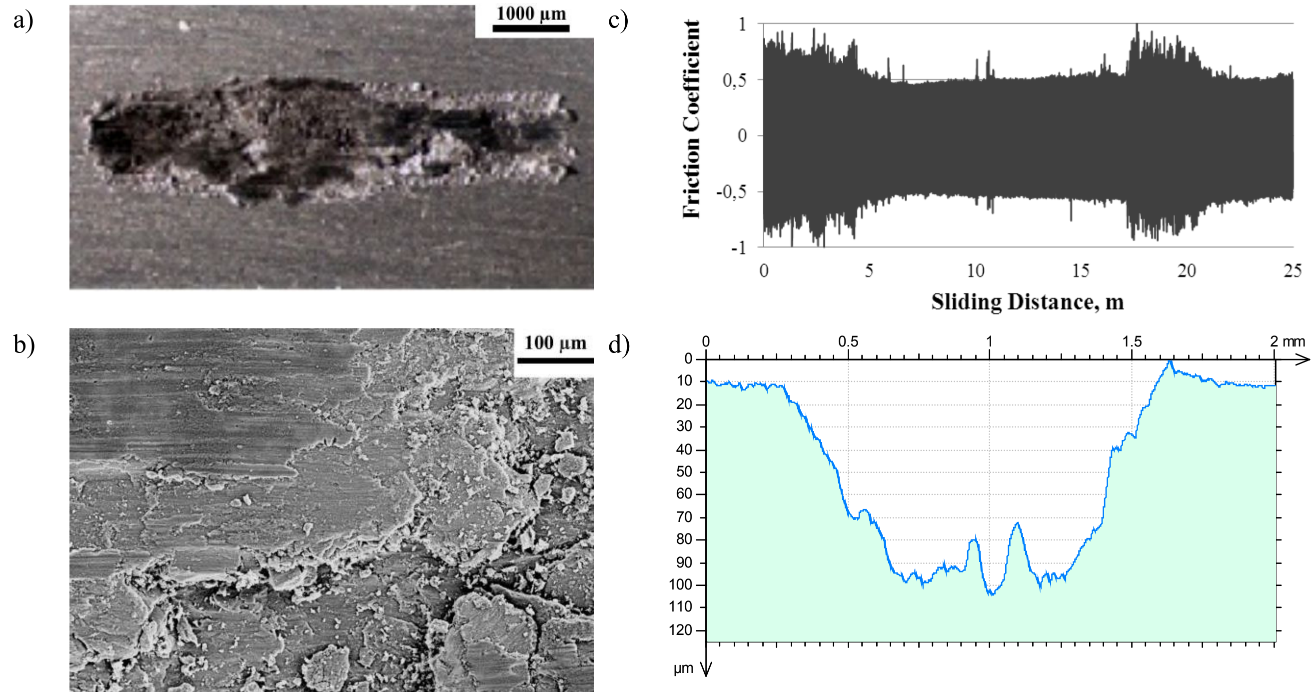


Fig. 2. Results obtained after the wear tests of the hot extruded AlMg1SiCu/0% MWCNT samples under a load of 5 N prepared by 5 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

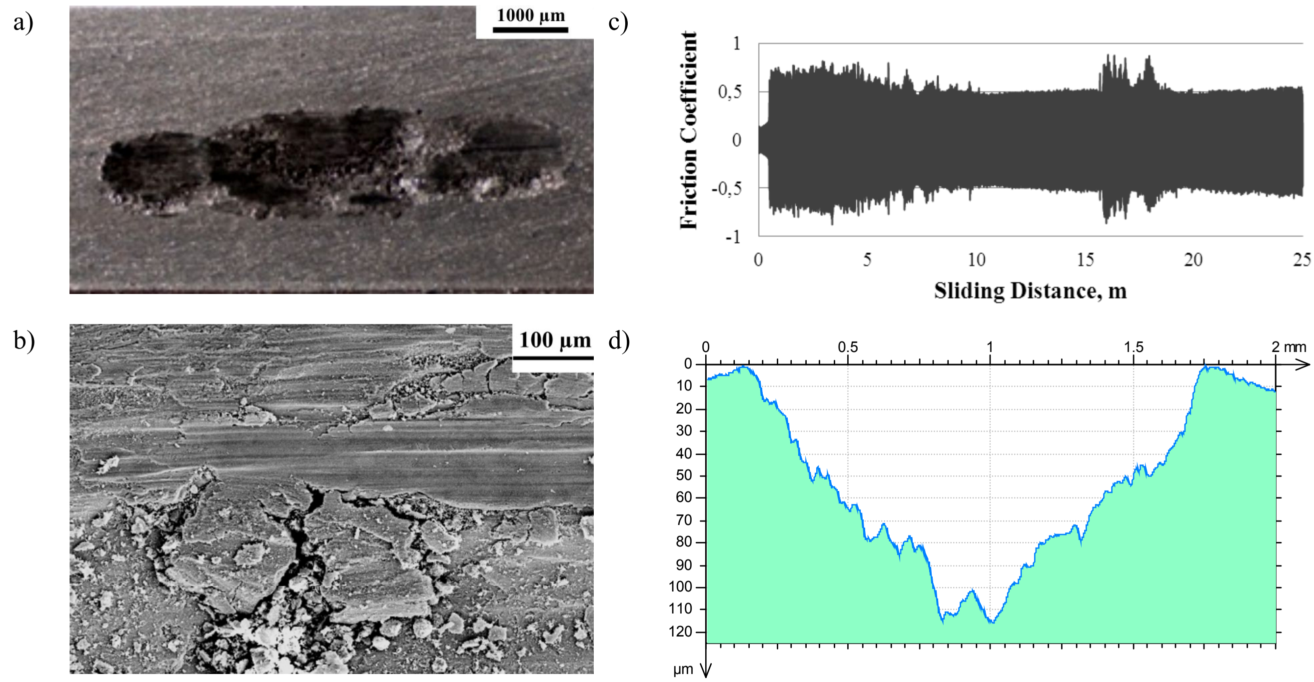


Fig. 3. Results obtained after the wear tests of the hot extruded AlMg1SiCu/0% MWCNT samples under a load of 5 N prepared by 10 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

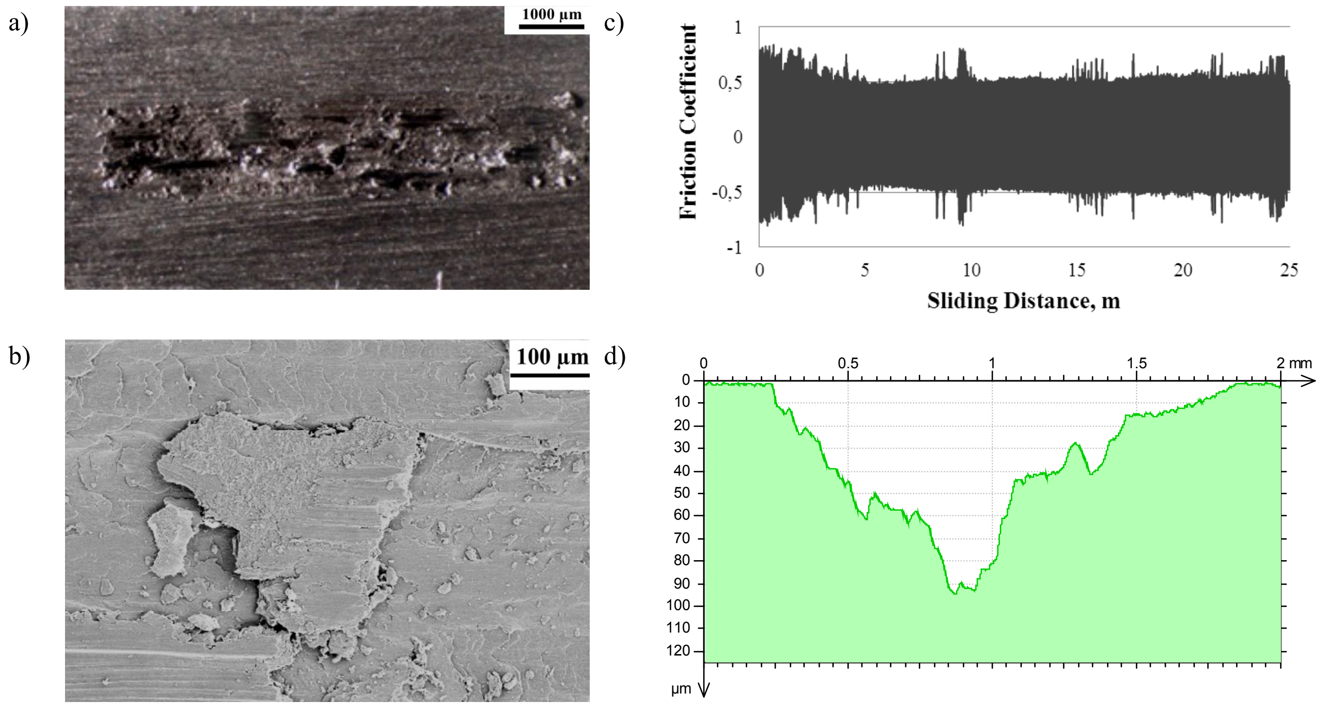


Fig. 4. Results obtained after the wear tests of the hot extruded AlMg1SiCu/2% MWCNT samples under a load of 5 N prepared by 5 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

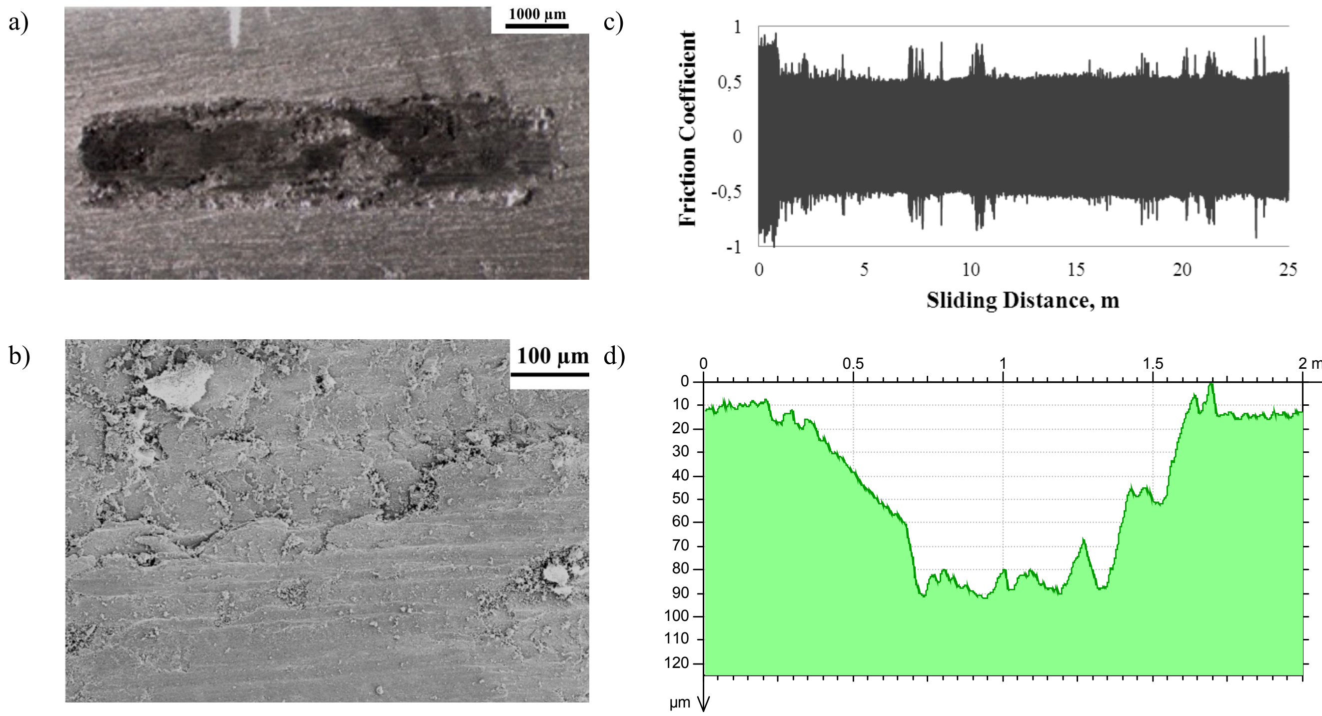


Fig. 5. Results obtained after the wear tests of the hot extruded AlMg1SiCu/2 %MWCNT samples under a load of 5 N prepared by 10 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

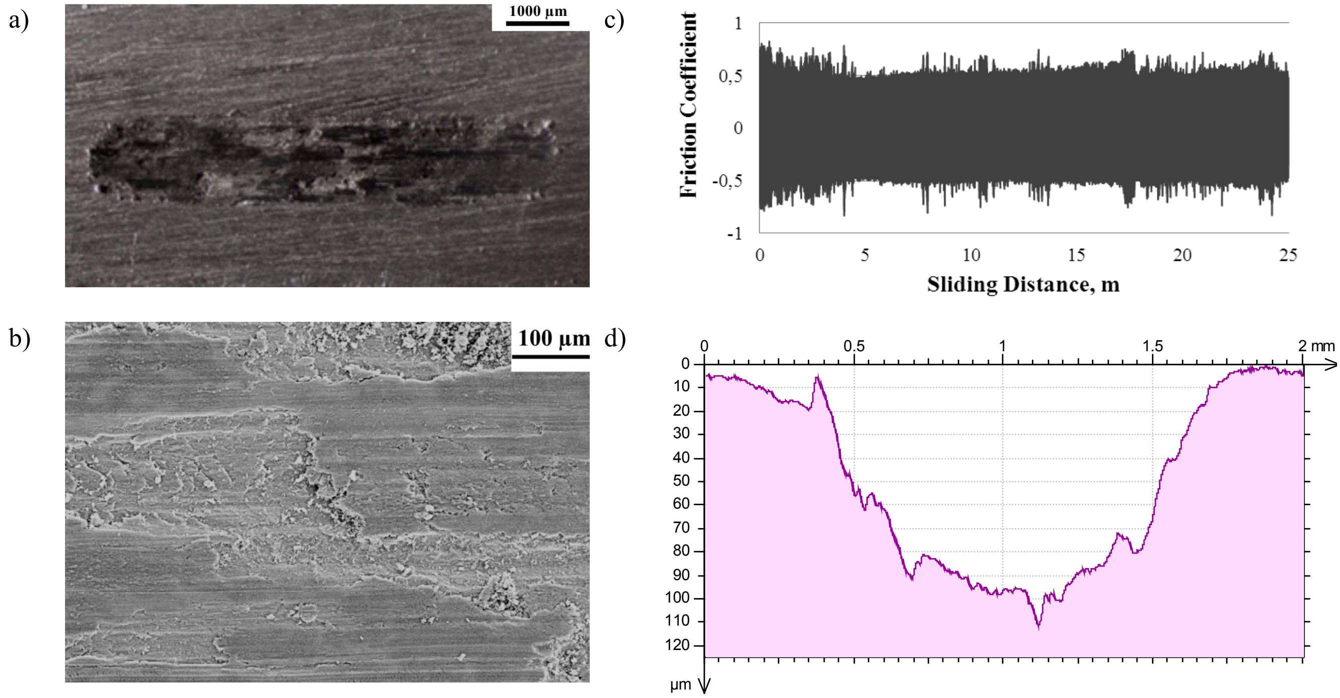


Fig. 6. Results obtained after the wear tests of the hot extruded AlMg1SiCu/5% MWCNT samples under a load of 5 N prepared by 5 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

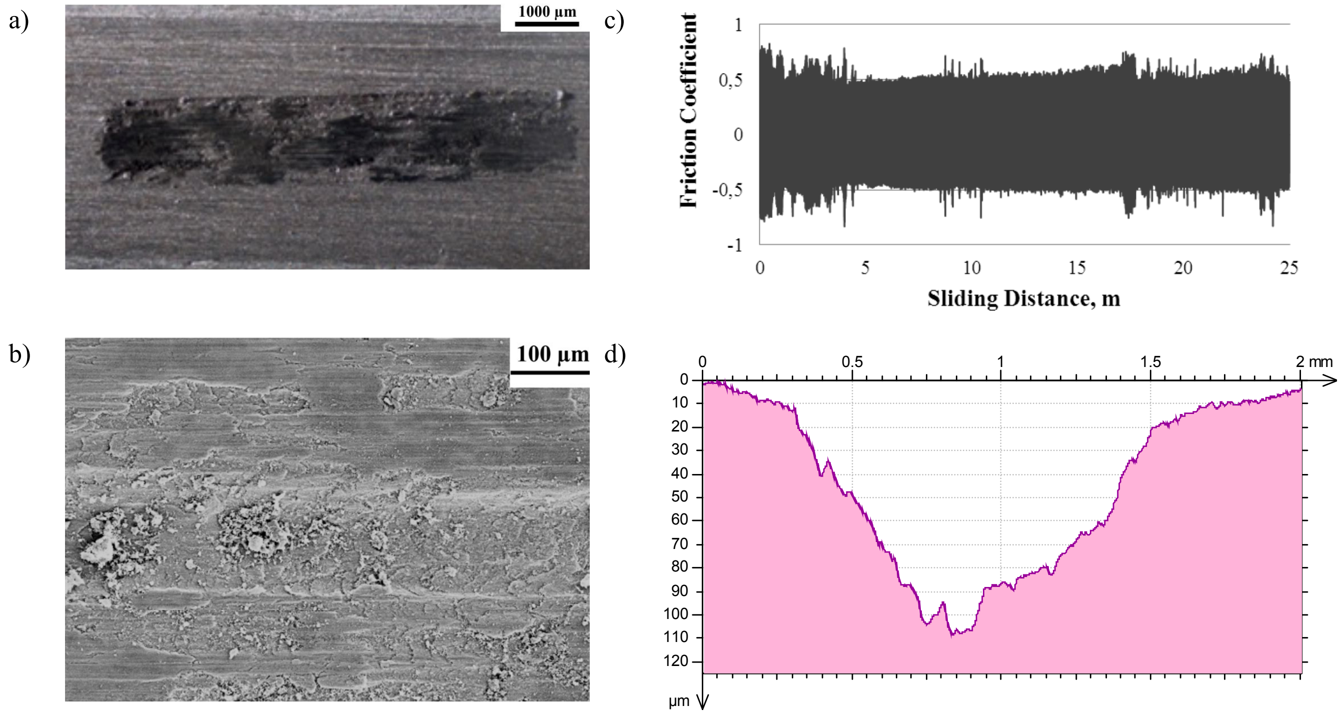


Fig. 7. Results obtained after the wear tests of the hot extruded AlMg1SiCu/5% MWCNT samples under a load of 5 N prepared by 10 h of high-energy mechanical milling: a) wear track, b) worn surface, c) friction coefficient, d) cross-section profile

Table 2.
Microhardness of the nanocomposites

MWCNT content in Al alloy powder. vol.%	Milling time, h	Microhardness, $HV_{0.1}$
AlMg1SiCu	unmilled	61
AlMg1SiCu + 0% MWCNT	5	101
	10	129
AlMg1SiCu + 2% MWCNT	5	132
	10	157
AlMg1SiCu + 5% MWCNT	5	158
	10	168

The best results of wear rate are achieved for the nanocomposites with 5 vol.% of MWCNT. On the Fig. 6b the least amount of crater on nanocomposite surface can be seen. According to the extensive dislocation density produced by the mechanical milling process. The reason is the increase of barriers across dislocations movement which limits their movement. The dominant wear mechanism is a severe plastic deformation of the matrix that results in high wear rate.

The results of the influence of the MWCNT concentration and milling time on the microhardness on extruded nanocomposites are given in Table 2. It has been observed that the hardness of the nanocomposite increases with increasing milling time as well as with growing MWCNT's content up to 168 HV.

4. Conclusions

The results have confirmed that self-lubricating composite reinforced by MWCNT has better tribological properties under dry wear test compared to unreinforced and another amount of MWCNT.

The friction coefficient for nanocomposites reinforced with MWCNT is slightly lower, and has smaller fluctuation as compared to the unreinforced alloy.

The microhardness of the nanocomposite increases with increasing milling time as well as with increasing concentration of MWCNT.

Acknowledgements

The works have been implemented within the framework of the project entitled "Determining the importance of the effect of the one-dimensional nanostructural materials on the structure and properties of newly developed functional nanocomposite and nanoporous materials", funded by the Polish National Science Centre in the framework of the "OPUS" competitions, headed by Prof. Leszek A. Dobrzański. The project was financed by the National Science Centre granted on the basis of the decision number DEC-2012/07/B/ST8/04070.

Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME'2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

References

[1] S. Simoes, F. Viana, M.A.L. Reis, M.F. Vieira, Improved dispersion of carbon nanotubes in aluminium nanocomposites, Composite Structures 108 (2014) 992-1000.

[2] L.A. Dobrzański, M. Macek, B. Tomiczek, Effect of carbon nanotubes content on morphology and properties of AlMg1SiCu matrix composite powders, Archives of Materials Science and Engineering 69/1 (2014) 12-18.

[3] H.J. Choi, S.M. Lee, D.H. Bae, Wear characteristic of aluminum-based composites containing multi-walled carbon nanotubes, Wear 270 (2010) 12-18.
[4] A.D. Moghadam, E. Omrani, P.L. Menezes, P.K. Rohatgi, Mechanical and tribological properties of self-lubricating metal matrix nanocomposites reinforced by carbon nanotubes (CNTs) and graphene - A review, Composites Part B 77 (2015) 402-420.
[5] A.M.K. Esawi, K. Morsi, A. Sayed, M. Taher, S. Lanka, The influence of carbon nanotube (CNT) morphology and diameter on the processing and properties of CNT-reinforced aluminium composites, Composites Part A 42 (2011) 234-243.
[6] E.M. Sharifi, F. Karimzadeh, Wear behavior of aluminum matrix hybrid nanocomposites fabricated by powder metallurgy, Wear 271 (2011) 1072-1079.
[7] J. Stein, B. Lenczowskia, N. Frety, E. Anglaret, Mechanical reinforcement of a high-performance aluminium alloy AA5083 with homogeneously dispersed multi-walled carbon nanotubes, Carbon 50 (2012) 2264-2272.
[8] D. Poirier, R. Gauvin, R.A.L. Drew, Structural characterization of a mechanically milled carbon nanotube/aluminum mixture, Composites Part A 40 (2009) 1482-1489.
[9] M. Fattahia, N. Nabhania, E. Rashidkhanib, Y. Fattahic, S. Akhavanc, N. Arabianc, A new technique for the strengthening of aluminum tungsten inert gas weld metals: Using carbon nanotube/aluminum composite as a filler metal, Micron 54-55 (2013) 28-35.
[10] L.A. Dobrzański, E. Jonda, W. Pakieła, M. Bilewicz, Improvement of wear resistance of the hot work tool steel by laser surface feeding with ceramic powders, Archives of Materials Science and Engineering 60/1 (2013) 64-71.
[11] A.M. Al-Qutuba, A. Khalil, Wear and friction behavior of Al6061 alloy reinforced with carbon nanotubes, Wear 297 (2013) 752-761.