International Journal of INNOVATIVE AND INFORMATION MANUFACTURING TECHNOLOGIES
Donetsk National Technical University & International Union of Machine-Builders
International Journal of Innovative and Information Manufacturing Technologies, SHEI "Donetsk National Technical University"; 58, Artyoma Street, 83001 Donetsk, UKRAINE, Tel.: +38 062 305 01 04, Fax: +38 062 301 08 05, E-mail: tm@mech.dgtu.donetsk.ua, http://iimt.donntu.edu.ua

EFFECT OF MANUFACTURE TECHNOLOGY ON PROPERTIES OF ALUMINIUM ALLOY WASTES-BASED BEARING COMPOSITES FOR PRINTING MACHINES

ROIK Tatiana[1], GAVRISH Anatoliy[2], KYRYCHOK Peter[3], VITSUK Yuliya[4]

Publishing and Printing Institute; National Technical University of Ukraine "Kyiv Polytechnic Institute"; 1/37, Yangelya Street, 03056, Kyiv, UKRAINE
Corresponding author: ROIK Tatiana, roik2011@gmail.com

Submitted 22.09.2013; accepted 25.09.2013

Abstract. The paper studies the effect of the technological parameters for the production of new aluminium alloy wastes-based antifriction composite materials on the structurization and tribotechnical properties at friction (bearings perform at a sliding speed of 1.0 m/sec and a pressure up to 5.0 MPa in air).
The study focuses on the features of structure formation in the composite with Al–alloy AK12MMgN wastes matrix, their role in friction behavior of new composite material under severe operating conditions. It was shown the principle possibility of successful use of the valuable industrial colour metals grinding wastes for manufacturing of effective friction parts for printing machines.
Keywords: metal grinding wastes, aluminium alloy AK12MMgN, physical mechanical properties, tribological characteristics, friction parts, printing knife-machines.

1. Introduction

The main task in the development of new composite antifriction materials is to increase the life of machines and mechanisms, for example, printing equipment.

Among antifrictional composite materials intended for severe operating conditions of higher loads and sliding speeds materials based on aluminium are well known [1–3].

Numerous studies show that aluminium alloys improve the tribotechnical characteristics of friction parts [1, 4]. This is due to their original physical properties. For example, aluminium-based materials are characterized by low density, high heat conductivity, which makes them highly wear-resistant owing to intensive heat removal from the friction area.

Now existent parts of friction elements in printing machines (especially of cast aluminium alloys) aren't capable to satisfy the modern severe operating conditions of printing equipment, for example, knife-machines [3].

It is connected with their unsatisfactory antifriction properties of such parts, which are the sequent of existent making technologies imperfection, which are not able to ensure high quality of contact surfaces [3, 4].

Composite aluminium antifriction materials have advantages over cast ones because they have not such essential defect like liquation. But they have high cost which is connected with high cost of powder production technology. These factors limit the usage of composite materials based on aluminium.

At the same time the big resource reserves exist in machine-building industry in the world now. There are large in number of grinding powder wastes of ferrous and colour metals.

Such metal powder wastes are appeared at the finish abrasive grinding of different parts in machine-building plants [5]. They consist of large number of valuable alloy elements (Ni, Cu, V, Mg, W, Si, Ti and others) and aren't used in subsequent production cycle because they are polluted by grinding abrasives and cutting emulsion. Therefore, such wastes are usually dumped. It concerns aluminium alloys too.

Therefore, it is of theoretical and practical importance to establish the possibility of usage of aluminium grinding powder wastes for effective materials manufactures, and their effect on the friction behavior of aluminium-based materials in severe operating conditions of printing machines.

The objective of the present paper is to develop an antifrictional aluminium wastes-based composite material for increased-duty conditions (sliding speed and higher pressure) and to study the formation of a film on the working surfaces of a friction pair at a sliding speed of 1.0 m/sec and a pressure to 5.0 MPa.

2. Experimental procedure

The subject of the study is new material of aluminium alloy AK12MMgN (silumin) powder grinding wastes which were chosen like a basis for the new composite antifriction material.

Silumin AK12MMgN consists of different alloy elements (Table 1).

Table 1
Chemical composition of Silumin AK12MMgN

Element, wt.%											
Si	Cu	Mg	Zn	Sn	Mn	Cr	Ni	Na	Fe	Ti	Al
11.0-13.0	1.2-1.6	0.9-1.2	0.3-0.5	0.01-0.02	0.3-0.6	0.05-0.2	0.8-1.3	0.05-0.1	0.5-0.8	0.05-0.2	rest

Assortment of valuable alloy elements (Table 1) in microparticles of alloy AK12MMgN powder wastes is able to ensure high level of tribotechnical, physic and physic-mechanical properties of material.

Preparation of Powder Charge. The complex making technology that consists of two main stages was developed during he researches:

- First stage - technology of alloy AK12MMgN powder wastes *regeneration* (cleaning from abrasive and cutting emulsion);

- Second stage –technology of new material manufacturing, including preliminary cold pressing and next hot pressing of specimens.

The technology of wastes regeneration has been created during the experimental researches.

This *regeneration technology* has 3 stages for obtaining clean aluminium alloy AK12MMgN powders:

1. Drying of moisture;
2. Annealing components of cutting emulsion;
3. Electric static (separating) cleaning against abrasives.

After regeneration the remains of abrasives were come to 5% and it was confirmed by metallographic analysis.

Overview of alloy AK12MMgN powder wastes microparticles after regeneration has been presented on Fig. 1.

Compaction. Last time well-known methods of hot pressing have taken the special significance for making antifriction materials of high density [1, 6, 7].

These methods were used for development of the new composite materials on silumin AK12MMgN wastes- based *manufacturing technology*.

During the experiments the technological properties were determined, for example, packed density of regenerated silumin powder is 0.75 g/cm^3. This parameter is a technological characteristic for ensuring the constant shrinkage.

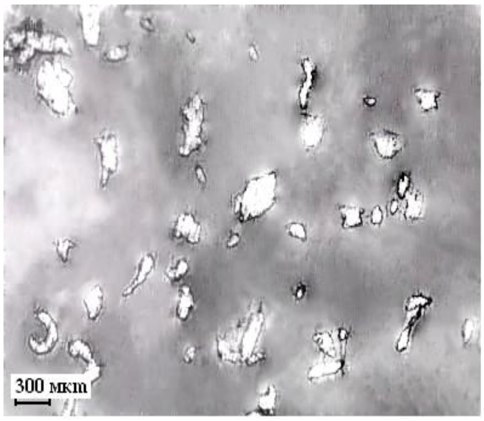


Fig. 1. Overview of alloy AK12MMgN powder wastes microparticles after regeneration (on plastic plate), ?32.

Manufacturing technology has 2 stages:

1. *Preliminary Cold pressing.* Experimental samples have been manufactured at specific pressure 500 MPa and had a relative density 0.92. Pressing was carried out at hydraulic press PSU-125 for cold pressing.

Experimental samples of regenerated alloy AK12MMgN were pressed at a room temperature in press-forms of different dimensions (for different tests):
1-in plug-and-socket press-form, dimensions 10·40 mm;
2- in bushing press-form, O32·12 mm;
3- in cylindrical press-form, O32 mm.

2. *Final Hot pressing.* A stage of cold pressed samples hot pressing was realized at the temperature of external heating 400 ^{0}C and loading 300 MPa. Hot pressing was carried out at hydraulic press for hot pressing with maximum nominal pressure 1.6 MN. This technological operation is necessary for obtaining maximum density of composite samples to avoid volume oxidation of materials during their next exploitation on air in printing machines.

Examination Techniques. The microstructure and abrasive remains of obtained new material AK12MMgN grinding wastes-based were researched by quantitative metallographic methods (Fig. 1) at images analyzer Leco IA3001 IMAGE SYSTEM (USA).

Initial intermetallic compounds were studied on unetched microsections. Second intermetallic compounds were identified using scanning electron microscopy method (SEM) by electron microscope SELMI-200 (Ukraine) (Fig. 2).

Chemical composition of friction zones was studied using micro-X-ray analysis by scanning electron microscope EVO 50XVP (Germany, Carl Zeiss).

Physical mechanical properties were studied by standard methods [8-10].

Tribological tests were performed on a VMT-1 friction testing machine where the specimen was held against a rotating steel disc. The line dimensions of the specimen were fixed after every 1.0 km sliding distance. The dimension losses of specimens were calculated from the difference in dimensions between the initial and final dimensions after friction tests.

The parameters for tribotechnical tests are the following: V = 1.0 m/sec; P = 5.0 and 7.0 MPa; in air, the counterface is made of 45 steel – unalloyed carbon steel, C=0.45 wt.% (HRC=51–55); shaft–pin friction pair; lubricant - machinery industrial oil I-20; sliding distance -2.5 k□m.

Conditions of tribological tests correspond to real operating conditions of printing machine friction units. Dimension loss measurements were fixed after every 500□m sliding distance approximately.

The antifriction properties of the cast alloy [6] and new composite were determined under liquid sliding conditions for comparison of properties between the cast aluminium alloy and new material of aluminium alloy AK12MMgN grinding wastes-based.

3. Experimental results and discussion

We produced a heterogeneous composite material consisting of a metal matrix and inclusions of abrasive remains. In turn, the structure consists of high-alloyed α-solid solution on the base of aluminium. In this solid solution there is an eutectic which is formed at silicon content of 11.6 wt.% which corresponds to the Al–Si phase diagram [7] and seats as cellular structure of solid solution grains in whole matrix volume (Fig. 2).

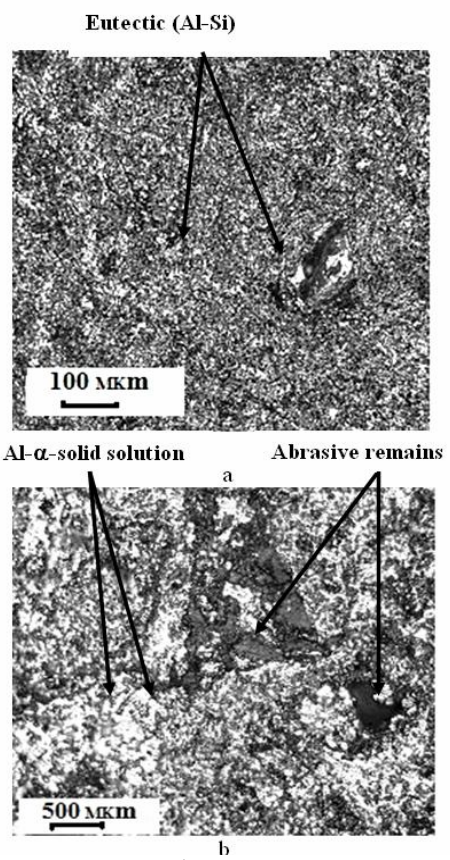


Fig. 2. Microstructure of material AK12MMgN grinding wastes-based: etched microsection, ×100 (a), ×500 (b), etching in 5% NaOH

Complicated heterophase metallographic structure of composite material AK12MMgN grinding wastes-based formation took place as a result of hot pressing process.

Moreover a big quality of alloy elements (Table 1) causes the formation of a large number of fine reinforcing phases– intermetallic compounds. These are $CuAl_2$ (θ-phase), Mg_2Si, $NiAl_3$ (ε-phase) (Fig. 3).

Structural researches (Fig.3) are evidence of the presence of the initial and second intermetallic compounds as the reinforcing phases - T($AlCu_2Mn$), S(Al_2CuMg), $MnAl_6$, $TiAl_3$, AlFeSi (α-phase), N(Al_7Cu_2Fe) in metal matrix. These phases have a high density and they are uniformly distributed over the entire matrix in the samples. It is beneficial effect to decrease the grain size and increase physical mechanical and antifriction properties.

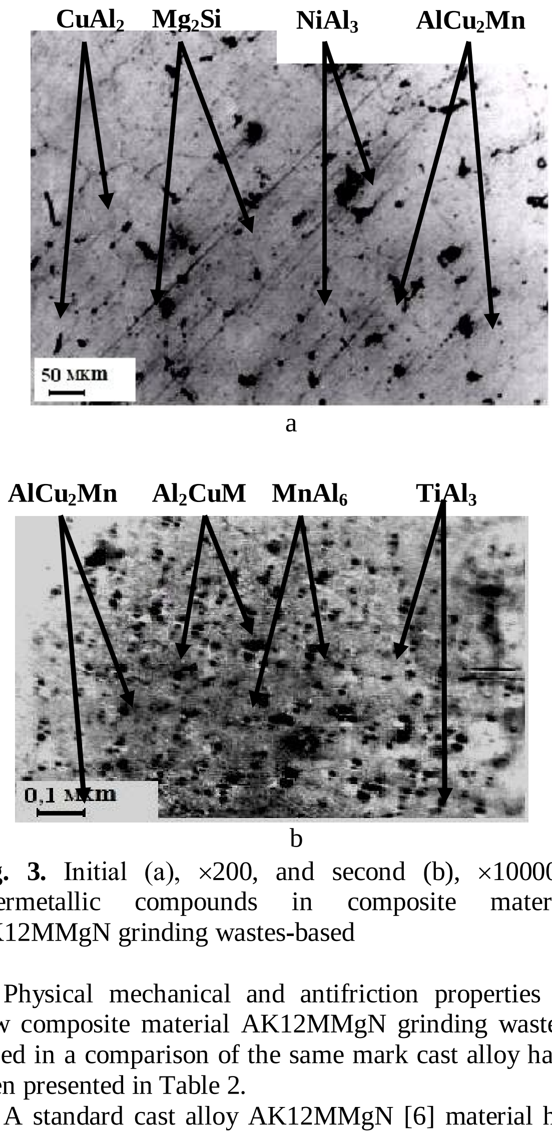


Fig. 3. Initial (a), ×200, and second (b), ×100000, intermetallic compounds in composite material AK12MMgN grinding wastes-based

Physical mechanical and antifriction properties of new composite material AK12MMgN grinding wastes-based in a comparison of the same mark cast alloy have been presented in Table 2.

A standard cast alloy AK12MMgN [6] material has been also tested for comparison with new composite material of alloy AK12MMgN grinding wastes-based

Analysis data shows (Table 2) the composite material of AK12MMgN grinding wastes-based doesn’t yield to cast one by physical mechanical properties (Ultimate strength, Hardness, Impact elasticity), has a much lower coefficient of friction and wear rate than those of cast alloy AK12MMgN used in similar operating conditions, especially under loads up to 7 MPa.

Table 2
Physical mechanical and antifriction properties of materials

Material	Ultimate strength, MPa	Hardness, HB, MPa	Impact elasticity, kJ/m^2	Friction coefficient at loading, MPa		Linear wear, ?m/km at loading, MPa		Linear wear of counterface, ?m/km at loading, MPa		Limited temperature, ^{0}C	Limited load, MPa
				5.0	7.0	5.0	7.0	5.0	7.0		
AK12MMgN grinding wastes-based	180-185	550-570	0,18-0,30	0,0075-0,0080	0,03-0,032	3,9	14,8	signs	6,4	130	7
Cast **AK12MMgN** [6]	186	620	0,30-0,40	0,0250	0,08-0,087	6,0	33,2	2,5	18,6	120	3,5

These facts can be explained by the essential distinctions of cast and composite material structural formation. Such distinctions appear in consequence of different principles of their synthesis.

Cast alloy AK12MMgN manufactured by traditional moulding method has liquations of alloy elements which becomes apparent as chemical composition heterogeneity in volume of material. As against cast alloy new composite material of wastes-based was produced (final hot-pressing method) of AK12MMgN powder microparticles which are microingots without any liquation. As a result the structure of such composite material is homogeneous and ensures higher level of properties.

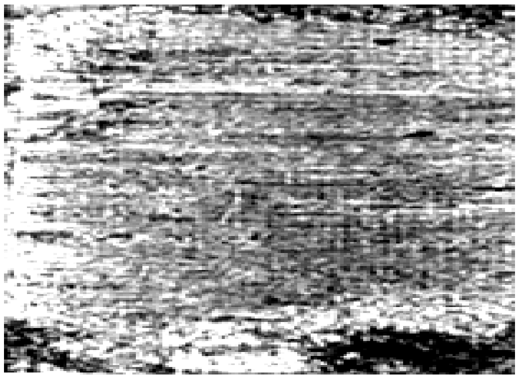
The full-scale tests of new composite material of AK12MMgN grinding wastes-based showed increase of wear resistance 2.24 times more than cast alloy AK12MMgN.

It is explained that the liquid lubricant is inoperative on the surface of cast AK12MMgN as it is squeezed out from the friction zone under pressure at high operating loadings of printing machines. In such case the cast aluminium antifriction materials have dry friction contact with the counterface because the surfaces remain unprotected, juvenile.

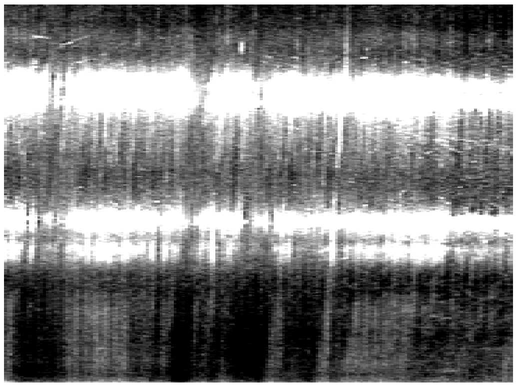
Composite material of AK12MMgN grinding wastes-based has porosity 2-3% where liquid lubricant is stopped and can run out to contact friction surfaces under operating loads.

Surface topographies of friction zones of new material and counterface have been presented on fig. 4.

Investigations of contact surfaces (Fig. 4) after tribological tests show the friction surfaces of new composite material AK12MMgN wastes-based and counterface are not damaged, have high quality, and are usable.



a



b

Fig. 4. Antifriction material AK12MMgN grinding wastes-based (a) and counterface of 45 steel (b), ×5

The scanning electron microscopy and micro-X-ray of the friction surfaces after tribological tests confirms the presence of chemical elements both composite material and counterface (Fig. 5, 6).

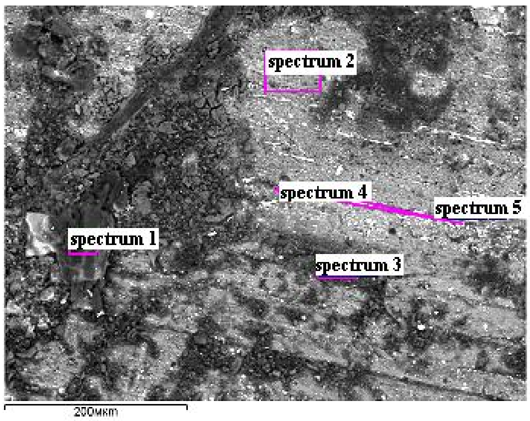


Fig. 5. Electron image of composite material friction surface after tribological tests at load P=5.0 MPa (in reflected electrons)

Distribution of chemical elements on friction surface after tribological tests at load P=5.0 MPa was as follows, at.%:

Spectrum 1: C – 54.49; O – 41.47; Na – 0.31; Al – 0.50; Si – 0.53; P – 0.12; S – 0.29; Cl – 0.13; K – 0.15; Ca – 0.10; Fe – 0.03.

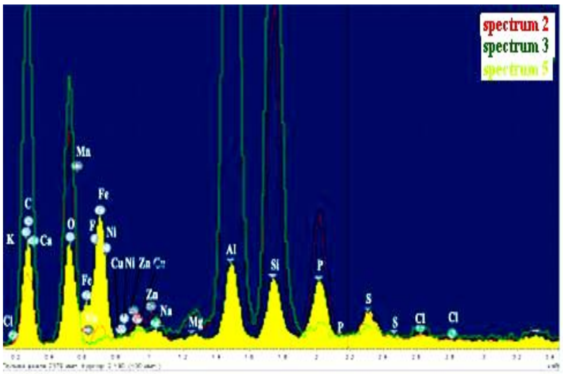


Fig. 6. Spectrums of composite material friction surface after tribological tests at load P=5.0 MPa (spectrums 2, 3, 5)

Spectrum 2: C – 37.42; O – 28.63; Na – 0.56; Mg – 0.37; Al – 18.22; Si – 8.04; P – 3.08; S – 0.50; Cl – 0.12; K – 0.20; Ca – 0.25; Mn – 0.10; Fe – 1.23; Ni – 0.23; Cu – 0.69; Zn – 0.25.

Spectrum 3: C – 60.28; O – 22.64; Na – 0.20; Mg – 0.17; Al – 8.99; Si – 6.87; P – 0.17; S – 0.08; Cl – 0.11; K – 0.10; Fe – 0.12; Ni – 0.11; Cu – 0.16.

Spectrum 4: C – 49.52; O – 21.35; Na – 0.59; Mg – 0.23; Al – 13.42; Si –7.03; P – 1.94; S – 0.39; Cl – 0.11; K – 0.15; Ca – 0.18; Fe – 4.36; Ni – 0.23; Cu – 0.50.

Spectrum 5: C – 51.03; O – 21.17; Na – 0.87; Mg – 0.27; Al – 3.23; Si –2.48; P – 2.32; S – 0.77; Cl – 0.17; K – 0.18; Ca – 0.21; Fe – 16.29; Ni – 0.29; Cu – 0.74.

As is evident from fig. 5, 6 friction zones in addition to main chemical elements of composite silumin specimen have been saturated with carbon, iron and oxygen. It's connected with high loads on friction pair, participation of 45 steel counterface and air at friction process, also chemical elements (K, Cl, Na, Ca, S) of liquid lubricant (industrial oil) remains were present.

Since composite material has residual porosity liquid oil penetrates to pores and they are microvessels for oil in a case of lubricant emergency stopping.

4. Conclusions

The research results obtained in such a way confirmed adequacy and practicability of composite antifriction aluminium alloy wastes-based material making technology. Such data illustrates availability to use the high-alloyed valuable and inexpensive grinding wastes of aluminium alloy AK12MMgN as initial resource for manufacturing quality friction parts for printing machines.

Next experiments will be devoted to the research of phase composition in friction zone and its effect of antifriction aluminium alloy wastes-based material tribological properties.

References

1. Rupa Dasgupta Aluminium Alloy-Based Metal Matrix Composites: A Potential Material for Wear Resistant Applications. ISRN Metallurgy, vol. 2012, p. 14. Article ID 594573.
2. Miller W.S., Zhuang L., Bottema J., Wittebrood A.J, Smet P. De., Haszler A., Vieregge A. (The Netherlands, Belgium, Germany) Recent development in aluminium alloys for the automotive industry. Materials Science and Engineering. Taiwan, Vol. 280, 2011, issue **1**, 37-49.
3. Roik T. An influence of alloy elements for structure and properties of antifriction materials from silumin wastes. Donetsk: DNTU, 2003, **26**, 44-51.
4. ROIK T., GAVRISH A., GAVRISH O. et al. Patent No. 34407 Ukraine, C22C 21/02. Composite bearing material on the base of aluminium; National Technical University of Ukraine "KPI": 11.08.08, Bulletin No. 15.
5. Roik T., Kyrychok P., Gavrish A. Composite bearing materials for increased exploitation conditions. Kyiv: NTUU "KPI", 2007.
6. Fedorchenko I., Pugina L. Sintered Composite Antifriction Materials. Kiev: NaukovaDumka, 1980.
7. Gavrish O., Vitsuk Yu., Roik T., Gavrish A., Voytko S. New technologies of manufacturing standard products. Kiyv: NTUU "KPI", 2012.
8. ISO 148-1: 2009. Metal materials. Test of Impact elasticity by Charpy impact machine.
9. ISO 6506-1: 2005. Metal materials. Brinell hardness.
10. ISO 6892: 1984. Metals. Methods of tension test.