International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 16 (2017) pp. 6045-6049

Designing of Laminated Structure of Antifriction Powder Composite

Yu.V. Kontsevoi*, A.G. Mejlakh A.B. Shubin and E.A. Pastukhov. I.S. Sipatov**

Institute of Metallurgy of Ural Branch of Russian Academy of Sciences, 620016, 101 Amundsen st., Ekaterinburg, Russia.
**Corresponding author*

**ORCID 0000-0001-5156-3573, ** ORCID 0000-0001-9357-0317*

Abstract

A new high-density copper-based powder antifriction composite with layered structure was developed and produced by rolling technique. Iron powder with intermetallic shell (Fe_2Al_5) is a reinforcing component of the antifriction composite. The reinforcing component was produced by thermal-vibrational treatment of iron and aluminium powders mixture in a cladding unit. Complex reinforcing of copper matrix occurs in the result of rolling, namely, iron core is deformed plastically and forms reinforcing fibers, but fragile intermetallic shells are crushed in to pieces with size of 1 µm or less. The fine particles are distributed in the copper matrix uniformly. Additives of plumbum powder as solid lubricant are stretched in thin plates. The hardness and friction moment of 80Cu-5Fe_2Al_5-5Fe-10 Pb (wt.%) antifriction composite were 980 MPa and 0.4, respectively. These values are in compliance with state of the art requirements for bearing shells used in automotive industry.

Keywords: Composite material, powders, cladding, rolling, heat treatment, dispersive hardening, structure, mechanical properties

INTRODUCTION

Development of a new antifriction materials with improved functional properties is important due to a progressive increase of intensity and loading of main friction assemblies of machines and units [1]. The composite materials production by powder metallurgy technique fundamentally is most promising because this method has almost no limits for material compositions selection and while designing of material structure to provide required functional properties [2].

As a rule, powder wear-resistant materials have composite structure comprised of plastic matrix (e.g. copper or aluminium) and solid inclusions. Wear-resistant copper-based composites with reinforcing inclusions of Cu-C granulates[3], Al-Cu-Fe quasicrystals doped by B and Al_2O_3 [4], nanoparticles Al_2O_3 [5], DIN 100Cr6 steel powder [6], cast iron [7] and some other additives are well known. Sulphides, plumbum, graphite in different forms are used as antisplitting components (solid lubricants) [8].

The aim of this work was to develop a new copper-based antifriction composite with laminated structure for further development of bearing shells. Fe-Al intermetallic and iron particles are chosen as reinforcing components, while plumbum is selected as antisplitting component [9]. It was assumed that Fe-Al intermetallics will be crushed to the fine state and reinforce copper matrix, while plastic iron and plumbum particles will become fibrous or plates in the result of rolling. Therefore, the obtained composite will have layered structure, that prevents fatigue destruction [10,11].

EXPERIMENTAL DETAILS

Powders of copper (PMS-M4 grade, 0.5-10 µm, JSC Uralelectromed) and plumbum (PSA grade, 30-40 µm, JSC Tyumen accumulator plant), aluminium (PAD 6 grade, 5-6 µm), and iron (PGhR 3.160.28 grade, 160 µm JSC GK Iron element) were initial materials for antifriction composite development. We produced reinforcing components with iron core and Fe_2Al_5 intermetallic shell. Cladding of iron powder were carried out by vibro-thermal treatment using preliminary vibro-aeratic mixing of iron and aluminium powders [12]. The key cladding parameters are the vibrational amplitude of chamber 8 ÷10 mm, the frequency - 35÷40 Hz, the temperature - 750 ºC, the treatment time - 30 ÷ 40 s[13]. This technique enables us to adjust parameter of cladding within the wide range and provides obtaining of composite powders with predetermined structure and phase composition [14]. Mixing of powder components were carried out at 1:10 mass ratio of charge materials and balls [15] and their treatment in vibroaeratic unit [16,17]. Microstructure and chemical analysis of powder mixtures and samples cross sections was carried out using Carl Zeiss EVO 40 SEM equipped with BSD detector and attachment for EDS analysis. Several cross-sections of pressed and sintered samples (dimensions 10x10x55 mm) were used for chemical composition measurement and further comparison. Brinell hardness measurements were carried out using TSh-2M testing machine. Fabrication mill DUO LPS – 82 was used for rolling. Antifriction testing of bimetal bearing shells was carried out using friction machine 2070 SMT-1 at rotating speed of counter sample of 850 rpm. Testing was performed in accordance with State Standard 26614 – 85 (Powder

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 16 (2017) pp. 6045-6049

antifriction materials. Test method for determination of tribotechnical properties). The time dependence of friction force moment was measured.

RESULTS AND DISCUSSION

Microstructure of iron particle with Fe-Al intermetallic coating is shown in Fig.1.

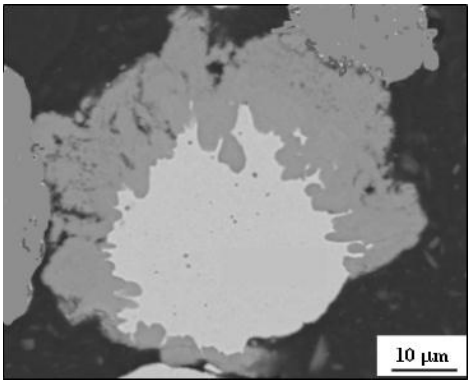
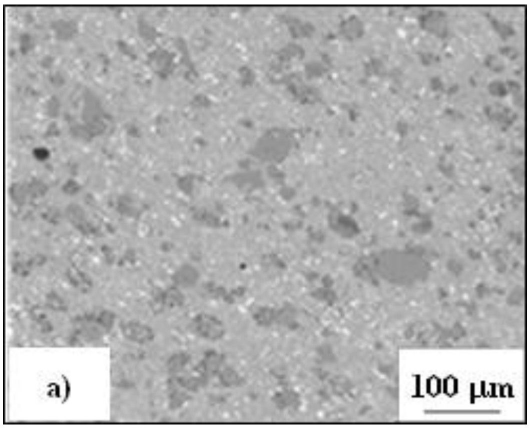


Figure 1. Iron powder plated by aluminium: Fe_2Al_5 - dark grey shell, Fe - light grey core.

It was assumed that such structure of the material make possible complex reinforcing of copper matrix in the result of rolling [18]. Namely, soft iron core will be deformed plastically and reinforcement fibers (filaments, plates) will be formed, but brittle ferroaluminides will be crushed into particles (less 1 µm) and distributed uniformly in copper matrix.

Analysis of powder mixture homogenization in ball mill and vibroaeratic unit (Fig.2) has revealed that both methods provide the similar results, but the key difference is in treatment time. While the chemical analysis of charge samples has revealed that the divergence of elements content was ±0.25 wt.%. For example, the optimal mixing of powders was achieved by vibroaeratic and ball mill treatment after 60-90 sec and 7.2-$9.0 \cdot 10^3$ sec, respectively. The best result of mixing were achieved at the parameters of 40 Hz and 9 mm.



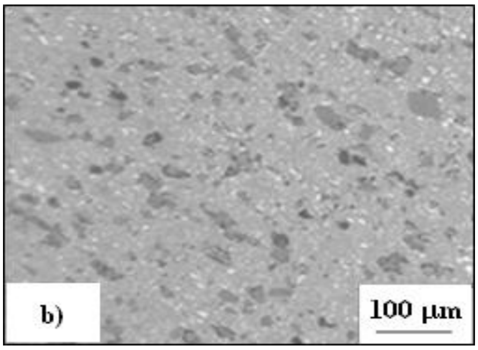


Figure 2. The microstructure of specimens having composition of 80% Cu, 5 % Fe_2Al_5, 5% Fe, 10 % Pb (wt.%) Powder mixing was carried out in a) ball mill, b) in vibroaeratic unit.

Notably, that fine powder are prone to conglomeration, but vibroaeratic mixing promotes destruction of conglomerates [17], e.g. it is seen from comparison of Figs. 2a and b. Hence, vibroaeratic method of mixing is the most promising one.

The lower porosity is, the higher strength properties are. Hence, optimization of composite consolidation was carried to reduce porosity. The strength properties of powder materials are estimated here by values of hardness. Consolidation of $Cu{-}Fe_2Al_5{-}Fe{-}Pb$ powder mixtures was carried out in steel rigid matrix and by rolling. Single-phase pressing at 700 MPa and further sintering at 730°C enables us to obtain samples with density within the limit of 0.76 ÷ 0.79, after additional pressing at 800 MPa and sintering at 800 °C the upper limit of density was 0.88÷0.9. Further increase of pressing conditions had no effect on composite density. The density of the composite was increased by rolling up to required values 0.98÷1.0. The dependence of hardness of pressed (700 MPa), sintered (730°C) and rolled $Cu{-}Fe_2Al_5{-}Fe{-}Pb$ composites on relative density and intermetallic concentration is shown in Table 1.

Table 1. Dependence of $Cu{-}Fe_2Al_5{-}Fe{-}Pb$ composite hardness on relative density and intermetallic content in the powder mixture.

№	Concentration of Fe_2Al_5 wt. %	Cobbing at rolling, %	Relative density	Hardness, HB MPa
1	5	0	0.73	280
2		60	0.92	670
3		80	1.00	980
4	10	0	0.56	220
5		50	0.81	685
6		75	0.94	1000
7	20	0	0.55	230
8		40	0.74	420
9		50	0.89	1050

It is seen from Table 1 that both factors influence on have effect on composite material hardness, while the major factor is the relative density. Further study was carried out using composite containing 5 wt.% of Fe_2Al_3 in powder mixture, since the lower intermetallics content is, the higher compactibility is, and the values of hardness are similar at acceptable cobbing.

Different types of press forming and heat treatment were used for formation of laminated structure of powder mixture (80 Cu, 5 Fe_2Al_5, 5 Fe, 10 Pb wt.%):

1 – pressing (700 MPa) and sintering of powder charge (inert atmosphere,730°C, 900 sec);

2 – rolling of the composite obtained by pressing and sintering (point 1) at various values of cobbing;

3 – pressing and sintering (point 1), rolling of sintered composite and repetative heat treatment;

4 – direct rolling of powder charge and sintering of rolled stripe;

5 – pressing of the powder charge sample with minimal relative density (0.5), consolidating rolling with 80% cobbing and sintering of the composite.

The effect of different types of press forming and heat treatment on structure of composite is shown in Fig.3.

Microstructure of sample treated in accordance with point 1 (with relative density 0.8) involves copper matrix with reinforcing elements and inclusions of solid lubricant (Fig. 3a). It is obvious that functional additives are in initial state in matrix, i.e. bulk inclusions (up to 60 μm) of iron, Fe_2Al_5, and spherical particles of plumbum.

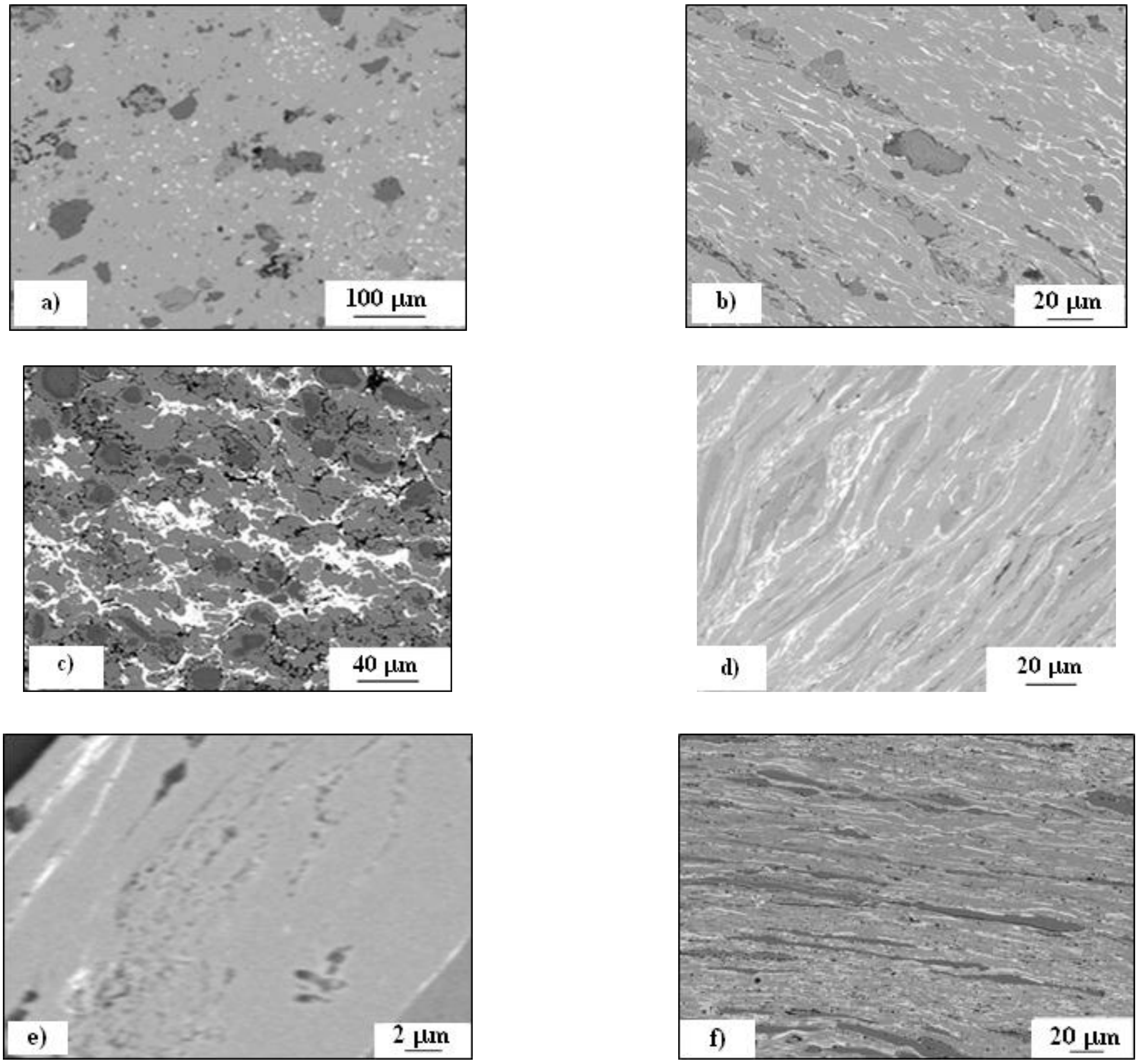


Figure 3. Dependence of composite microstructure made of powder mixture (80 Cu, 5 Fe_2Al_5, 5 Fe, 10 Pb wt.%) on manufacturing conditions (press forming and heat treatment). Phase constituents of microstructure on Figs. 3a)-f): Cu – light grey, Fe_2Al_5 black inclusions, Fe – dark grey, and Pb – white stripes. Cobbing, %: b) 40, c) 50, d) 70, e) 75 , f) 80.

It was found during pilot frictional testing that bulk inclusions act as abrasive and surface of counter sample is destroyed.

The sample treated in accordance with point 2 (Fig. 3b), 40% cobbing, components are elongated along rolling direction. Fe_2Al_5 particles are refined in 8-9 times, but iron particles form plane fibers. Plumbum inclusions are short and thin plates. Cobbing increase up to 50% (Fig.3c) does not plumbum to formation of iron reinforcing fibers, but plumbum forms lengthy and wide inclusions. Rolling at 70% cobbing (Fig.3d) provides obtaining of composite with predetermined fibrous structure with favourable distribution of additional components in copper matrix. However, almost all plumbum was smelted out of composite in the result of heat treatment required for rolling on steel stripe, so the samples obtained in accordance with point 3 have lost integrity.

To consolidate powder charge by rolling the powder mixture was scattered on steel support and rolled with total cobbing of 70-80% (point 4). The composite layer rolled on steel support was annealed at

730°C during 900 sec). Structure of the produced composite has fibrous structure; intermetallic reinforcing particles are crushed down required size (≤1 µm). However, the distribution uniformity of additional elements were broken by free shift of relatively large charge massifs and non-uniform flow of copper matrix. It is clear from Fig 3e) that plumbum aggregated at subsurface layer of coat, and reinforcing elements settled in middle layer. These additional elements and their distribution determine functional properties of the antifriction material. To obtain homogeneous structure of the antifriction material and exclude a possibility of powder massifs shift the treatment (point 5) was carried out. The preliminary weakly pressed sample (100 MPa) of powder charge with dimensions of 55×10×3 mm was used for rolling at the total cobbing of 80%. In the result of letter treatment scheme a microstructure of the antifriction layer complies with the task on structure designing (Fig. 3f). Namely, antifriction layer has fibrous structure, fine reinforcing intermetallic inclusion are uniformly distributed at the composite volume, iron reinforcing inclusions has striped shape and divide the composite volume on elemental layer. The relative density of coat is 0.99÷1.0. The results of tribological testing of the produced laminated composite (80 Cu, 5 Fe_2Al_5, 5 Fe, 10 Pb wt.%) are listed in Table 2.

Table 2. Dependence of frictional torque for laminated composite on testing time.

Time of testing, min	0	5	10	15	20	25	30	50	75	100	125	150
Frictional moment, Nm	1.35	1.04	0.81	0.51	0.42	0.36	0.33	0.51	0.28	0.21	0.20	0.29

It was found that bedding of antifriction material was during 1800 sec, than, than the value of friction factor becomes nearly constant 0.3÷0.4 until the end of testing. The value of friction factor meet the state-of-the-art requirements for materials of automotive plain bearings.

CONCLUSION

It was proposed a new composition of powder antifriction material based on copper. Unique reinforcing composite powder (Fe – Fe_2Al_5) was produced.

Manufacturing procedures providing production of required laminated structure of composite were determined Processes and regimes of steel stripe and antifriction composite co-rolling were found.

The new laminated composite with antifriction layer characterized by increased hardness, improved durability to fatigue destruction and frictional properties was developed.

ACKNOWLEDGEMENTS

This work was supported by Russian Science Foundation, project No 15-13-00029. The equipment of Ural-M Shared Research Centre was used to make this study.

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