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New Bimetal Bearing Shell for Internal Combustion Engine

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Abstract

Bimetal bearing shell with a new copper-based powder antifriction layer was developed for application in internal combustion engine. Laminated structure of the Cu − Fe_2Al_3 – Fe − Pb antifriction layer inhibits growth of fatigue failure cracks and provides strong adhesion to steel support. Iron powder with intermetallic shell (Fe_2Al_5) is a reinforcing component of antifriction layer. 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 fibrous, 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 lead powder as solid lubricant are also 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: antifriction material, powders, cladding, rolling, heat treatment, dispersive hardening, structure, mechanical properties

INTRODUCTION

The problems of materials friction and wear at high rubbing velocity arise in various branches of industry. The key reason for the loss of machines availability is improper operation of friction assemblies due to wear, tear, and appropriate breakdowns occur. Costs for repair and service of machines are higher in several times than their initial cost. This indicates that the problems of friction, wear, and lubrication of machines and units friction assemblies have technical and economical character [1]. Development of new antifriction materials for plain bearings (e.g. for conrod and main shells of internal combustion engine) is important due to a progressive increase of intensity and loading of main friction assemblies of machines and units.

Almost all vehicle manufacturers had started usage of bimetal shells with steel substrate and thin antifriction layer instead of white metal bearings since 2nd half of XX century [2-5]. Research and development of new materials having improved corrosion-resistance, abrasive and fatigue strength [6-9], low friction factor, high hardness, and appropriate plasticity are still undertaken [2]. For complex solution of the problem, it is required to develop antifriction coatings having the mentioned above properties, as well as improved adhesion to steel substrate.

Shells are produced by number techniques, e.g. plasma spraying of antifriction layer of steel substrate [10], ion [11] and vacuum-arc sputtering [12], electro contact and galvanic methods [13], etc.

The aim of this work was to develop bimetal shell, which have copper-based antifriction layer with laminated structure and strong cohesion to steel substrate, for internal combustion engines.

Fe-Al intermetallic and iron particles were chosen as reinforcing components, while lead particles are antisplitting components [14]. The ideas was that Fe-Al intermetallic would be crushed to the fine state and reinforce copper matrix, while plastic iron and lead particles would become fibrous or plates in the result of rolling. Therefore, the obtained composite would have layered structure and this should prevent cracks propagation of fatigue destruction [6-9].

EXPERIMENTAL DETAILS

Powders of copper (PMS-M4 grade, 0.5-10 μm, JSC Uralelectromed), lead (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. First, we produced reinforcing components with iron core and Fe_2Al_5 intermetallic shell by vibro-thermal treatment [15]. Such structure of reinforcing components makes possible complex reinforcing of copper matrix in the result of rolling. Namely, soft iron core is deformed plastically, and reinforcement fibres are formed, but brittle ferroaluminides are crushed into particles (less 1 μm) and distributed uniformly; this provides dispersion hardening of copper matrix [15].

Cladding of iron powder was carried out by vibro-thermal treatment of powder mixture of iron and aluminium [16,17]. Mixing of powder components was carried out by vibroaeratic treatment technique [18]. 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 composition measurement and further comparison. Heat treatment of samples was always carried out in protective atmosphere (neither reducing, nor oxidizing).

Brinell hardness measurements were carried out using Dura-vision Series testing machine (Emco-test). Co-rolling of steel substrate and antifriction composite was carried out by fabrication mill DUO LPS – 82 and CKBMM – 35 – 280 for search of optimal conditions for strong cohesive force between coating and substrate. Plasticity of coating was measured using Zwick/Roell Z050 machine by measuring of specific elongation of bimetal bearing shell before cracking of antifriction layer. Cohesive force were measured at 90° bend with radii equal to thickness of bearing shell at the antifriction layer side. Antifriction and wear 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 antifriction materials. Test method for determination of tribotechnical properties). The time dependence of friction force moment was measured.

RESULTS AND DISCUSSION

The powder charge having composition of 80% Cu, 5 % Fe_2Al_5, 5% Fe, 10 % Pb (wt.%) were produced by vibroaeratic mixing of initial powders. Chemical analysis of four charge samples revealed that the divergence of elements content in the charge was ±0.25 wt.%. The required strength properties of powder materials (in the present work – hardness) are improved at lower porosity. Hence, optimization of powder composite consolidation was required. Therefore, consolidation of Cu - Fe_2Al_5 - Fe – Pb powder mixture was carried out in steel press form and further rolling. Single-phase pressing at 700 MPa and further sintering at 730°C enables us to obtain samples with density up to 0.76 ÷ 0.79, after re-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. But rolling enables us to increase the density of the composite up to required values 0.98 ÷ 1.0. The study result of powder mixture composition and cobbing at rolling influence on density and hardness of composite material samples, which were preliminary pressed at 700 MPa and sintered (730°C, 15 min).

Table 1: Dependence of density and hardness of Cu − Fe_2Al_3 – Fe − Pb composite material pressed at 700 MPa and sintered (730°C, 15 min) on composition and cobbing (ε) at rolling.

No	Fe_2Al_3 concentration, %	ε, %	Relative density, %	Brinell Hardness, MPa
1	5	0	73	280
2		60	92	670
3		80	100	980
4	10	0	56	220
5		50	81	685
6		75	94	1000
7	20	0	55	230
8		40	74	420
9		50	89	1050

It is revealed from Table 1 that the considered parameters influence on hardness and density, while the key factor is density. From our point of view, the addition of 5 wt.% of Fe_2Al_3 is optimal for the material, due to ideal density and appropriate hardness value.

We investigated the structure and main properties of the composite material (80Cu-5Fe_2Al_5-5Fe-10 Pb wt.%) depending on types and schemes of forming operations and their combinations.

Pressing of powder charge with further sintering and rolling at various values of cobbing provide us a possibility to produce composite material with fibrous structure. Heat treatment of antifriction composite material is required for further knurling on steel substrate. Almost all lead was get out from the latter composite material during heat treatment and the integrity of the sample was lost. Hence, direct rolling of charge and sintering of rolled composite stripe was carried out for production of antifriction composite.

The mixture of powders was scattered over steel substrate and rolled at 70÷80% total cobbing. The rolled samples were annealed at 730°C during 15 min. The microstructure of produced composite material is shown in Fig. 1a.

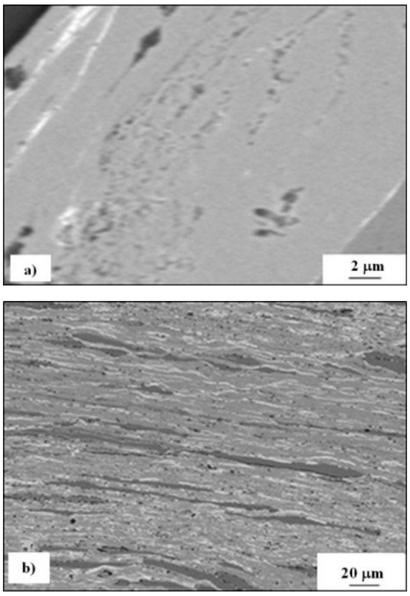

Figure 1: Dependence of the composite microstructure (80Cu-5Fe_2Al_5-5Fe-10 Pb wt.%) on powder charge state before rolling: a – powder mixture, b – pressed powder. Microstructure description: Cu – light grey fibres, Fe_2Al_5 black spherical inclusion, Fe – dark grey, and Pb – white stripes.

Antifriction layer had laminated structure, and reinforcing elements were crushed down to required size (1 µm or less), as shown in Fig 1a. However, uniform distribution of additional elements was broken due to free shift of relatively large charge massifs. It is clear from Fig 1a, that lead aggregated at subsurface layer of coat, and reinforcing elements settled in middle layer. Naturally, the absence of components uniform distribution cannot provide required properties of the antifriction composite. Hence, it was necessary to find a technique to obtain homogeneous structure of antifriction coating. To avoid a free shift of powder aggregates, we used preliminary pressing (100 MPa) of powder charge, so parallelepiped 55×10×3 mm was obtained. This sample was also co-rolled with steel substrate at the previously mentioned parameters. The image of obtained antifriction coating microstructure is shown in Fig. 1b. The microstructure of antifriction layer complies with the task on structure designing. Namely, antifriction layer has fibrous structure, fine reinforcing intermetallic inclusion are uniformly distributed in volume of the composite, iron reinforcing inclusions has striped shape and divide the composite volume on elemental layer, this prevents cracks propagation of fatigue destruction [6,9]. Lubricating lead became elongated thin plates and distributed uniformly in the composite. The relative density of antifriction layer was 0.99÷1.00. This material seems to be a good for antifriction bushing production. However, investigation of antifriction layer cohesion to steel substrate and plastic properties had revealed that the letter processing type is inappropriate. The reasons for this are loss of lead by antifriction layer and low cohesive force between composite and substrate due to a large number of operations for antifriction layer production.

Finally, the procedure of antifriction layer formation was combined with coating, i.e. weakly pressed composite powder stripe was placed on steel substrate, then required structure and density of antifriction layer was obtained in the result of co-rolling. The last stage was the heat treatment at 730 ºC, the duration time 30 min. There are three simultaneous processes: recrystallization annealing of steel stripe, sintering of antifriction layer and its diffusive conjunction with substrate.

Operation of antifriction powder stripe forming were made using fabrication mill (rollers diameter 82 mm) with predetermined gap of 1.5 mm. To achieve the required stripe density (50-55%), the predetermined forward force was applied by bar pusher at rolling. The operation of antifriction and steel stripes co-rolling was one-step. The deformation degree of steel stripe was determined at values of 40, 50, and 60%. At these conditions, the antifriction stripes were deformed on 60, 78, and 85%, respectively.

The dimensions of produced bimetal bearing shells are listed in Table 2.

Table 2: Dependence of main dimensions of bimetal bearing shells on deformation degree resulting from rolling

Degree of deformation, %	Total thickness of bimetal bearing shell, mm	Thickness of steel substrate, mm	Thickness of antifriction layer, mm
40	2.01	1.79	0.22
50	1.65	1.48	0.17
60	1.36	1.21	0.15

At cohesion testing of layered composite, it was established that there was delamination in bend zone of samples rolled at 40% deformation. While samples rolled at 50 and 60 % deformation have good cohesion, i.e. there was no splits or delamination at bending tests. We concluded that co-rolling at 50% or higher deformation degree of antifriction and steel stripes is required to produce bimetal bearing shell of high quality.

For testing of plastic properties of antifriction layer, we used samples obtained at 50 and 60% deformation degree. It was revealed that there was no cracks in antifriction layer until appearance of rapture neck in steel. Hence, it was concluded that antifriction layer plasticity has the value of steel (δ = 25%) or even higher.

It is necessary to note that bimetal bearing shell samples rolled at 60% deformation degree have antifriction layer structure with higher elongation of overlapped iron fibres in comparison with other ones. This regime is appropriate to obtain the most favourable for antifriction layer structure.

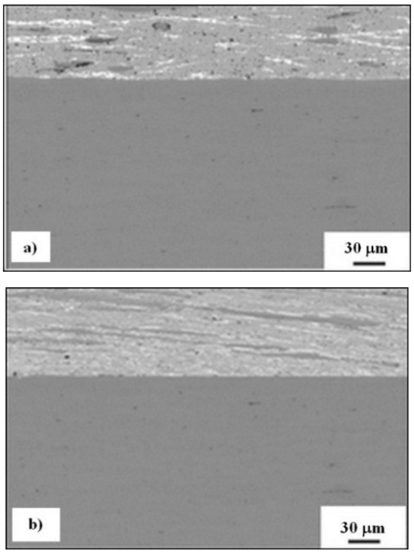

Figure 2: Microstructure of bearing shells obtained by rolling at 50% (a) and 60% (b) deformation degree.

The results of antifriction properties testing of produced bimetal bearing shell in comparison with plain bearing of 1VD-FTV engine (Toyota) and pure copper are shown in Fig. 3.

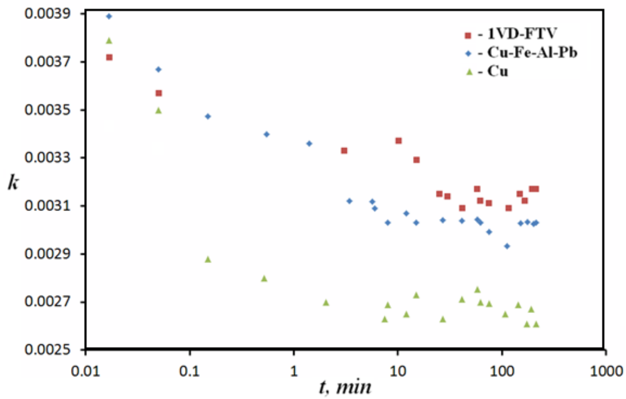

Figure 3: Dependence of frictional moment on bearing shell testing time

It is seen from Fig. 3 that the frictional moment of the new bimetal bearing shell is of the same level as industrial sample.

CONCLUSIONS

Optimization of copper-based composite antifriction material was carried out. The optimization became possible owing to development of new reinforcing composite core-shell (Fe – Fe_2Al_5) powder.

Manufacturing procedures and appropriate regimes were found, application of rolling enables us to produce antifriction composite having predetermined layered structure.

New bimetal bearing shell was developed by co-rolling of antifriction composite and steel substrate. The bimetal bearing shell has demonstrated improved characteristics: hardness, plasticity, friction factor, resistance to fatigue fracture and wear.

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