

The investigation of the wear of composite coatings of Zn-15Cu-20Al-5O-5C and Zn-30Cu-20Al-5O-10C on the surface of a crankshaft bearing

H. HAZAR*, O. CIHAN^a

Department of Automotive Engineering, Technical Education Faculty, Firat University, Elazığ/Turkey

^aDepartment of Mechanical Engineering, Hakkari University, Hakkari/Turkey

In this study, 6LD400 Lombardini crankshaft bearing internal surface was coated with two different zinc based alloys by atmospheric plasma spraying method. Coatings and matrix microstructure were analyzed with the Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). When the images of SEM samples are examined, a pore structure with wear tracks is seen. In wear test, in the loads applied, the least weight loss was found in the bearing coated with Zn-15Cu-20Al-5O-5C alloy. Average hardness value is found to be 52,5 HV which is accepted as the ideal bearing surface structure in bearing coated with Zn-30Cu-20Al-5O-10C alloy.

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1. Introduction

Plasma is defined as an intensified gas consisting of an equal number of free electrons and positive ions [1]. Plasma coating method enables the combination of the layer with reinforced surface properties and a base metal with a layer of different features [2,3]. Plasma has two important advantages the first of which is that it is comparatively at a high temperature, and secondly it provides a better heat conduction for the substance. The bigger gets the temperature difference between the heated environment and heated material, the higher the heating speed will be [4]. As it is used in numerous fields in the automotive sector, crankshaft bearing internal surface can be coated by plasma coating method.

The small part of connecting rod moves on vertical axis of cylinder in axial or linear direction. In the meantime bearing provides the connection between the great part of the connecting rod (lower end) and the crankshaft bearing, and by this way the mechanism turns on the crankshaft. This bearing which binds connecting rod with crankshaft is called crankshaft bearing [5]. Bearings as parts of machines constitute the most important samples among metal parts contacting each other. In the lubricated bearings, if oil film between the moving parts is in a sufficient condition, the type of the bearing material is unimportant. Chemical reactions constituting films which firmly stick to the surface prevent wear of surface. But if the film is not a brittle structure and does not stick to the surface tightly, wear gathers a big amount of speed; because in the films, during the friction, tear occurs and breaking occurs at the point of connecting of material [6, 7].

The axially formation of the holes on the bearings mating of the surface arises from base wear mechanism [8]. Adhesive wear (Adhesion wear) is a wear type widespread in the machine parts. The base of this wear can be explained with theory welding bond. Especially, it is the metals which perform sliding friction and seem to be as metallographic structures. Also some parts of even well-polished surfaces connect slightly. On the surface, cold fusion of wear pair occurs with breakup of the oxide layer. During the sliding motion, rupture commences with a cut at these points. The abrasion causes scratches, that are wear, on the surface [9]. In order to reduce the rate of wear, the bearing material and rate must be properly chosen.

The required features of the bearing materials are: well compression and fatigue strength, durability against wear and corrosion, capability of embedding, that is it must embed the hard particles either available in the oil or coming from outside in order to prevent the abrasion wear into its own structure, low friction coefficient, a good capability of sticking, moreover easy machinability and must be cheap as much as possible. None of the bearing materials which have been used in the technique will be enough to fulfill all the requirements by itself and each bearing material has certain advantages and disadvantages [10]. Therefore, the use of an alloy as a bearing material can improve the surface structure.

Aluminum materials have high wear resistance in alloys [11]. Aluminum, due to such characteristics as lightness, good heat and electric conductivity, high corrosion resistance and easy machinability, is widely used in engineering practice and especially it has proven to become a widely-used material as a matrix material in the production of metal matrix composite [12]. Zinc base

alloys have a number of advantages in contrast to the traditional bearings [13]. These advantages can be summarized as high wear resistance, good castability and low cost [14, 15]. Bearings produced from the zinc based alloys show a good tribological feature under the static load [14]. The biggest advantage of the use of the zinc element is that it has high corrosion resistance [16].

The mechanical and tribological properties of material develop by adding copper to aluminum and zinc alloy [17]. Copper is a metal which can be transformed into fine wire and plate, and which has a high heat and electric conductivity, with a wide range of use in the domain [18]. Moreover copper has a good machinability and ductile [19].

Experimentally in this study, an available crankshaft rod journal bearing will be coated with two different zinc based alloys which are used in diesel engines of 6LD 400 Lombardini mark. In this way, the highness in the mechanical properties of the bearing, the improvement of the wear and friction behaviors, and consequentially the production of the bearings which prolongs crankshaft journal life are aimed.

In this study, inner surface of 6LD 400 Lombardini crankshaft bearing is coated with Zn-25Cu-20Al-5O-5C and Zn-30Cu-20Al-5O-10C alloys by the use of atmospheric plasma spray method. The wear rate of the coated bearings and matrix were studied, microstructures were examined through Scanning Electron Microscopy (SEM) and dispersive spectroscopy (EDS) and afterwards the micro hardness of the samples was investigated. The mixture proportions of coating powders and matrix was determined based on the literature research. The mixture proportions of coating powders and matrix at Table 1 was measured by EDS after coating process.

2. Materials and method

Inner surface of bearing was coated by atmospheric plasma spray method by using aluminum powders with %99.0 purity at the particle size of 20 – (-45) and copper with %99.0 purity at the particle size of 45 – (-90) μm and zinc powders with %99.0 purity at particle size of 45 – (-90) μm . As the undercoat powder, Ni20Cr at the size of 20 – (-53) μm was used. SEM images of the powders which will be coated on the main material were shown in Fig. 1, and the mixture proportions of coating powders and matrix were indicated in Table 1.

Table 1. Mixture proportions of coating powders and matrix.

Sample	Composition (wt. %)					
	Zn	Al	Cu	O	C	Sn
Matrix		76.82	0.99	4.08	10.45	7.66
S1	55	20	15	5	5	
S2	35	20	30	5	10	

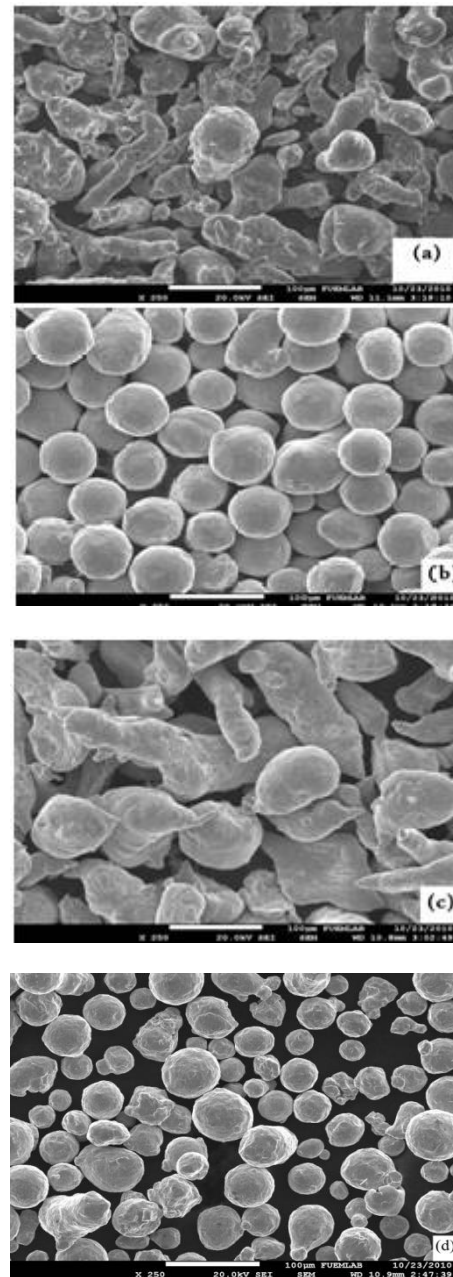


Fig 1. SEM images of powders used at coating: (a) Aluminum powder (b) Copper powder (c) Zinc powder (d) Ni20Cr powder.

Experiment was carried out on ring on ring type wear testing machine (Fig. 2) under static load and in lubricated environment. Samples were weighed on precious digital scales with 1/10000 g precision. After that, wear tests were performed at determined (42N, 67N and 92N) loads and at peripheral speed. The wear machine was stopped after each sample proceeded 1690 m for 30 minutes and thereafter samples with severed metal particles and oil on them were taken from the wear machine and cleaned with alcohol. After that, samples were weighed and weight losses were saved.

To examine the microstructure studies, samples which were taken from bearing were vertically placed into a cup

in order to take bakalite. After that, for the microstructure studies, lateral surface of samples were grinded up to 1200 mesh grind paper and polished with diamond paste (60/40 micron). For chemical etching, solutions of 5 g FeCl₃, 10 ml HCl and 240 ml alcohol were used. For the microstructures of each single sample the analyses of scanning electron microscopy (SEM) and energy

dispersive spectroscopy (EDS) were used. Furthermore, through applying 100 g load along with 10 seconds, micro hardness of samples were examined.

In this study, Sulzer Metco 80 KW 9MB model atmospheric plasma spray gun was used. Feed rate of this gun is 3 litres per hour. Thickness of coating is 280-330 µm and distance between guns – sample is 85mm.

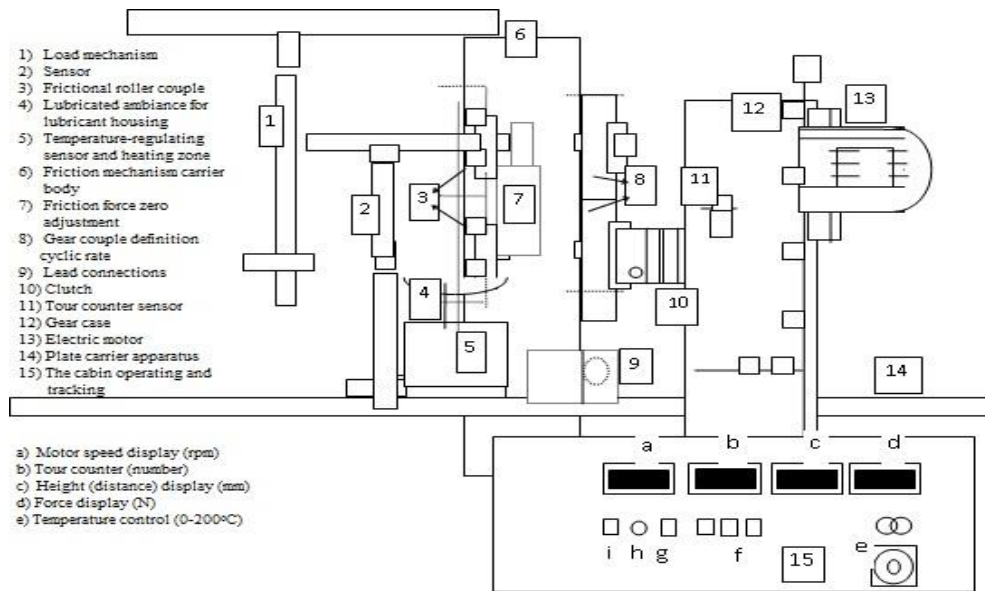


Fig. 2. Schematic View of Wear Testing Machine Ring on Ring. [20].

3. Results and discussion

In Fig. 3, the weight loss taking place for 30 minutes along the wear distance of 1690 m was studied at the graph formed with the results. Weight losses of matrix in 42-67-92N are respectively 0,0030-0,0042-0,0051 g. Weight losses of S1 in 42-67-92N are respectively 0,0006-0,0011-0,0019 g. Weight losses of PLINT S2 in 42-67-92N are respectively 0,0018-0,0029-0,0042 g. When the results are analyzed it is easily seen that the more applied load of the samples increases, the more weight losses of the samples increase. Therefore, with the increase in the load applied, an increase of weight loss in all the other bearings is observed. Moreover, all the studies conducted support this view [21, 22]. Compared to the S1 and S2, weight losses occurred in matrix after wear is maximum. High wear ratio in matrix can be explained as: with the rise in the load applied to the bearing, the temperature of the bearing increases and thus heat brings about wear along with itself.

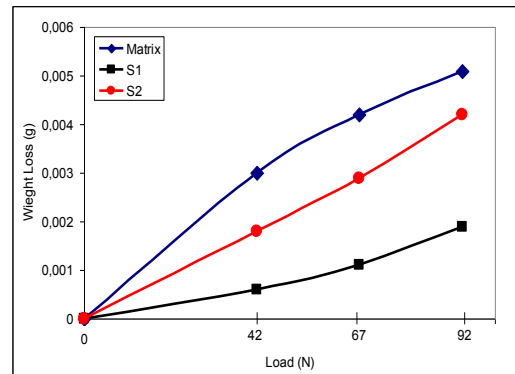


Fig. 3. Weight Losses of the Samples at 42N, 67N and 92N.

It is suggested that the friction layers formed on the sliding surfaces of the bearings produced by the Zinc-Aluminum based alloys act like solid lubricant in reducing friction in the bearing-shaft interface and thus, that these layers increase the wear resistance of the bearings [23]. From this perspective, it is seen that coated bearings are less worn than the matrix. On the other hand, the reason of a bigger weight loss in the matrix than the coated samples is that the bearing warms up more and loses its lubricate capability which finally results in more wear.

Bond structure of S1 alloy is stronger than S2 alloy bond structure. Therefore, it is thought that wear resistance of S1 alloy is better than other coated bearings and matrix. On the other hand, it is suggested that the hard aluminum oxide layer formed on the surface acts as a load-carrier and thus increases the wear resistance in the bearing; and the layer of zinc oxide especially in border and mixed friction conditions acts as a lubricant and enables the sliding [24]. In this respect, because of high zinc rate in the bearing coated with Zn-15Cu-20Al-5O-5C alloy as it increases the lubricity, the weight loss turned out to be less than matrix and the other sample.

SEM micrographs of bearing surfaces after wear were given in Fig. 4. Wear traces of samples were examined in X200 magnification. On surfaces of reinforced aluminum composite bearings, adhesive wear traces occur less than aluminum alloy bearings [25]. Examining SEM images in Fig. 4, wear traces in the coated bearings outnumber the wear traces in matrix. The reason for this is although the powder particles coated on the surface form a metallic friction, there are indeed no deep and wide lines on the surface of the bearing. These shallow wear traces can be seen as the results of the hardness of severed zinc, copper and aluminum particles. On the other hand, it is suggested that the friction layers occurred on the sliding surfaces of the bearings produced from Zn- Al alloys act as solid lubricant, and thus reduce the friction between the bearing-shaft, and therefore wear resistance increases [26]. Wear resistance on both bearings coated with two different Zn-Al based alloys is higher than it is in matrix. This view is also supported by the graph of the weight loss of the bearings.

The samples in microstructure pores were given Fig. 4. It is seen that the pores in coated samples are more than it is in matrix and are homogeneous. This condition, the intake of the lubricate and operating of lubricate film during contributes to operating of lubricate film [9]. It is deliberated that the homogeneity of the pores and their dispersing in a least dimension in the bearing structure enhance the lubrication at the first moment of operating or during the operation. It can be said that that the number of pores in the coated bearings are more than the matrix and that the dispersion of the pores in the coated bearings are in a homogeneous structure improve the lubrication of the bearing. Also a better lubrication in the bearing will increase the wear resistance [5]. Tribological properties in coatings depend on the speed and temperature of the particulates [22]. The fact that the speed and temperature of particulate in coatings are better, a better bonding of coating to the main material, dispersion on the surface of the coating and snappily solidification of the coating with coated bearings structure surface a stronger than matrix.

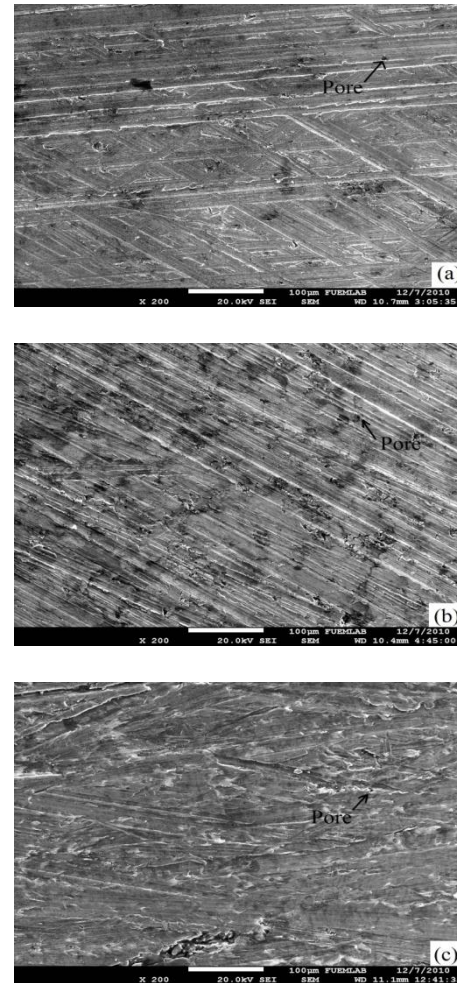


Fig. 4. SEM images of wear surface in the coated samples with (a) Zn-15Cu-20Al-5O-5C (b) Zn-30Cu-20Al-5O-10C (c) Matrix.

EDS analysis images of the zinc based coatings and matrix are given in Fig. 5. In the spectrum taken from matrix for EDS %75.34 Al, %9.95 Sn, %0.72 Cu, %4.06 O, %9.93 C are found. In the spectrum taken from the surface of the bearing coated with Zn-15Cu-20Al-5O-5C, %52.48 Zn, %15.18 Cu, %21.63 Al, %3.96 O, %6.95C is found. EDS analysis of Zn-30Cu-20Al-5O-10C of alloy coating is determined as %35.79 Zn, %28.48Cu, %17.72 Al, %5.24 O, %12.77 C. In point analyses conducted in coated bearings, the region has a zinc-rich concentration and in addition to this, aluminum, copper, carbon and oxygen elements are seen in the region.

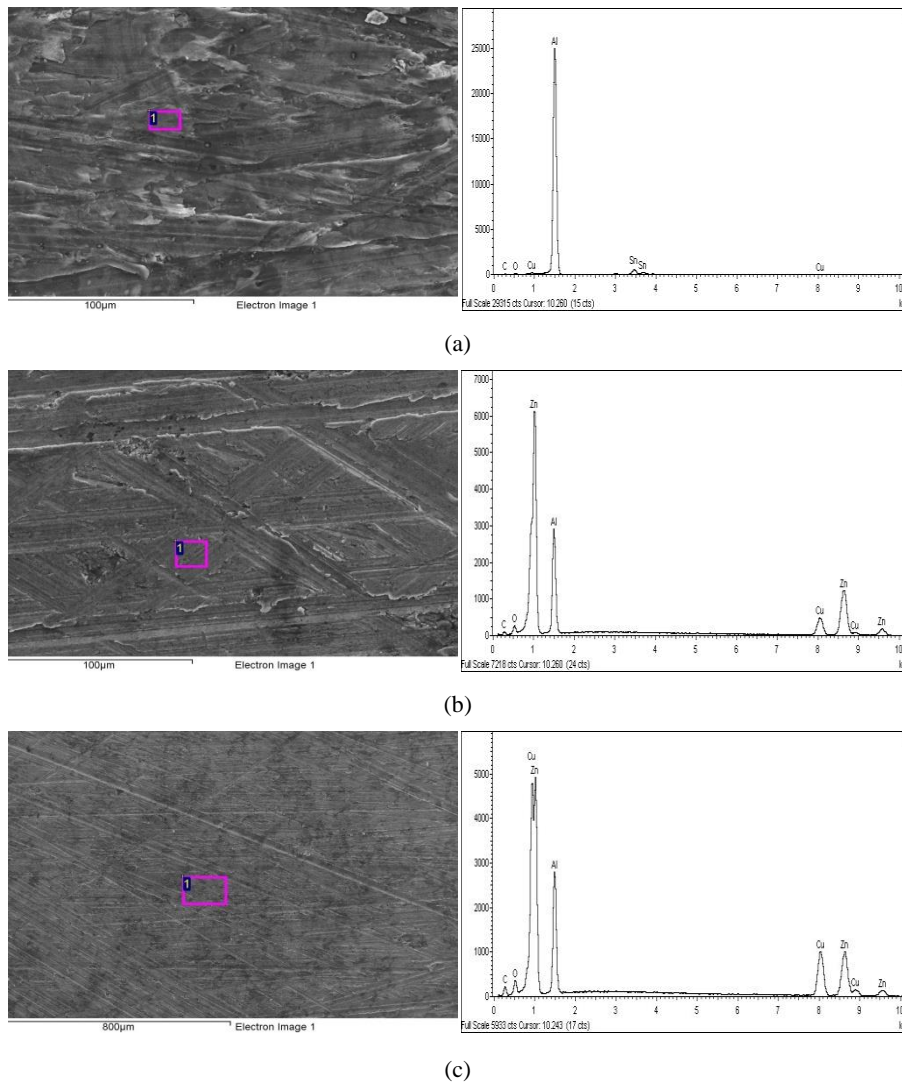


Fig. 5. EDS analyses (a) Matrix (b) Zn-15Cu-20Al-5O-5C (c) Zn-30Cu-20Al-5O-10C.

Crankshaft, matrix, and the average micro hardness values of S1 and S2 were given in Table 2. This table shows the average of the two hardness values taken from different regions in 10 seconds. Looking at Table 2, crankshaft is seen as the hardest material which is an expected situation. Crankshaft journals must be extremely hard compared to the used bearing material [5]. That the crankshaft is much harder compared to the bearing prevents the wear of the crankshaft by the bearing. Matrix with value of 42 HV proves to have the lowest hardness compared to crankshaft and the other samples. With the addition of materials like zinc, copper and aluminum to the structure of the bearing, as it is seen from the table, the hardness value of the bearing will increase. Savaskan and Azaklı at the end of their work, enabled the increase of the hardness of the bearing by coating SAE 65 bronze bearing with zinc based material [27]. On the other hand, after crankshaft, S2 sample follows as the hardest material. That S2 proves to be harder than S1 and matrix is because of the copper proportion it includes. Copper is harder than the other elements used in bearing and the proportion of it will

increase in composite materials, which will increase the hardness as well. In the study, the more copper proportion increased above %3 in Al-40Zn-Cu alloy, the more increased the hardness of the alloy [28]. Given this way, it can be said that the hardness value of S2 sample is found to be more than S1 and matrix.

As during operating, bearings are forced into dynamic stress; their resistance must be kept at optimum level which is related to the improvement of the structural properties of the bearings [5]. In the micro hardness test, S1 and S2 samples were found to be harder than matrix due to the material the sample contains. In this test, the hardness value of S1 is more suitable than S2, because S2, due to the high proportion of copper it contains, S2 sample is harder than from S1 sample up against the crankshaft. During the study, more friction will take place between S2 and crankshaft than S1 and matrix and by this way crankshaft will be more worn. As a result, crankshaft life will be shorter [29]. From this perspective it can easily be said that the hardness value of S1 is more suitable for the

crankshaft than S2 and matrix as it contains a comparatively low proportion of copper.

Table 2. Specimens microhardness values.

Material	Average hardness value (HV)
Crankshaft	221.5
Matrix	42
S1	52.5
S2	63.5

4. Conclusions

Zinc based alloys were coated by means of atmospheric plasma spraying method on bearing. In the wear test applied to matrix and coated bearings, the least weight loss was observed in Zn-15Cu-20Al-5O-5C sample. When the microstructure of the samples were examined, it is seen that it has a pore structure and there emerged wear traces on the surface; and these pore structures occurred more in coated bearings. These pores in the microstructure of the bearing increase the lubricity of the bearing. It is revealed that, compared to other bearing samples, the most suitable average micro hardness value in regard to the crankshaft life was Zn-30Cu-20Al-5O-10C alloy.

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*Corresponding author: hanbeyhazar@hotmail.com