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Evaluation of effect of alloy elements in copper based CuSn10 and CuZn30 bearings on tribological and mechanical properties

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ABSTRACT

Brass and especially bronze in copper based alloys are widely used as journal bearing material. Pure copper materials are not used as journal bearing material due to their low mechanical and hardness properties. These materials having acceptable tribological and mechanical performance give satisfactory results in journal bearings. In this study, tribological and mechanical properties of journal bearings manufactured from copper based CuSn10 bronze and CuZn30 brass were investigated. Moreover, the effect of alloy elements of Cu, Sn and Zn on tribological and mechanical properties of journal bearings was evaluated. SAE 1050 steel shaft (journal) was used as counter abrader. Wear experiments were carried out at 20 N loads, 1500 rpm for 2.5 h by using radial journal bearing wear test rig.

1. Introduction

In the past few years, wood, iron and skin have been used as journal bearing materials. Moreover, brass, bronze and white metal have also found some applications. Currently, in addition to these bearing materials, aluminum and zinc based materials are used as journal bearing materials. With technological improvements, self-lubricated sintered bearings are used where continuous lubrication is impossible and plastic materials are used in certain applications. Therefore, it is essential that the bearing material be chosen depending upon application area.

Wear resistance is one of the most important properties that journal bearings should posses. There are several studies and investigations dealing with wear resistance improvements of these materials [1–4].

Copper based materials are widely used as bearing material because they have high thermal and electrical conductivity, self-lubrication property, good corrosion and wear resistance [5,6]. The effect of tin on wear in copper based materials is important. Copper based tin bronzes that include tin are used as bearing material to have a high wear resistance [7]. Friction and wear properties of these materials can be improved by adding tin [8]. The tin bronze (90% Cu and 10% Sn) is the most suitable bearing material under corrosive conditions, at high temperatures and high loads [9].

Zinc based alloys were used instead of bronze during World War II as journal bearing materials to compensate for copper deficiency in Germany [10]. Zinc based alloys are used due to high strength, high hardness and good friction properties in several engineering applications. For this reason, these alloys can be used as journal bearing materials [11]. Zn based alloys are used because of their good physical, tribological and mechanical properties, low cost, high wear resistance as journal bearing materials. Tribological properties of these alloys are higher than that of bronze [12–15]. These alloys are important for high loading, low speed applications as journal bearing materials. Tribological properties of these alloys are better than those of bronze materials. They are preferred to Al alloy, and cast iron due to high non-seizure, mechanical and wear resistance property in journal bearing applications. Hardness decreased and bur friction coefficient and wear resistance increased by adding graphite [16]. Tribo-materials used have embability and high wear resistance for crank shaft at automobiles. These bearings have lead, tin, aluminum and copper. These elements are coated to steel bearing due to their superior [2,17–19].

Lead and tin based white metal alloys are used due to their antifriction property as bearing materials. These alloys are produced by casting and spray deposition method. These casting alloys contain intermetallic phase. The process variables during spray forming of babbit bearing metal alloy strongly influence the microstructure and porosity of the spray deposits. The wear rate of the spray-formed alloy is lower than that of the as-cast alloy. Wear properties of the spray-formed alloy are attributed to the decreased intermetallic phases and modification in the microstructure of the eutectic phases [19]. SnPbCuSb (white metal) alloys are important due to non-seizure and good wear resistance as journal

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Table 1
(a) Chemical composition of SAE 1050 wt-(%). (b) Chemical composition of bearings materials wt-(%).

(a)

Material	C	Si	Mn	P	S	Fe
SAE 1050	0.51	0.25	0.75	0.040	0.050	Balance

(b)

Materials	Cu	Sn	Zn
CuSn10	90	10	–
CuZn30	70	–	30

bearing material. These alloys are especially used in automotive applications as journal bearings [4].

Journal bearing materials are expected to have several properties such as low friction coefficient, high load capacity, high heat conductivity, high wear and corrosion resistance. These properties directly affect the fatigue and wear life [7–9]. Copper based bronze and brass materials, zinc–aluminum based materials, and tin–lead based materials have been widely used as journal bearings due to their superior wear properties [4–8,20,21]. Some metal bearings provide these properties.

In this study, friction coefficient, temperature values and wear losses of bearing–journal samples were determined by wearing [22] on radial journal bearing wear test rig designed specially for this purpose manufactured by copper based CuSn10 bronze and CuZn30 brass that were manufactured journal bearings and these materials that form was manufactured from Cu, Sn and Zn bearing tribological and mechanical properties was evaluated and effects to these properties of alloy elements have been determined. In addition, wear properties were investigated by determining effect to these properties of alloy elements in these bearing materials with wear surface optical and SEM images.

2. Experimental studies

2.1. Preparation of experimental materials

In this study, CuSn10 bronze, CuZn30 brass, pure Cu, Sn, and Zn bearing specimens were used as journal bearing and SAE 1050 was used as shaft. The chemical compositions of the journal and bearing materials used in the experiments were given in Table 1. Dimensions of bearing specimens were as follows: inner diameter is $10^{+0.05}$ mm, width is 10 mm, and outer diameter is 15 mm.

The specimens were worn by radial journal bearing wear test rig under lubricated condition. The wear losses were measured under lubricated conditions of 20 N loads 1500 rpm ($\nu = 0.785$ m/s velocity) and every 30 min for 2.5 h (7065 m sliding distance). The lubrication was accomplished by using SAE 90 gear oil. After wearing, the specimens were cleaned by acetone and were weighted using 10^{-4} g sensitive rig. The microstructures of wear surfaces were photographed using optical and scanning electron microscope.

Tensile, compressive, notch impact, three point bending, radial fracture and hardness was performed using ALŞA type tensile test rig depending on TS-138, and TS-269 (Turkish Standard) for mechanical properties. Moreover, the hardness was measured using a SADT HARTIP-3000 type.

2.2. Radial journal bearing wear test rig

Bearings materials in journal bearings are generally selected from materials which have lower wear strength than the shaft material, thereby lowering the wearing of the shaft significantly. Therefore, journal bearing wear test apparatus are designed to examine the wearing of bearing materials. In this study, a special bearing wear test apparatus has been designed to examine the wearing behavior of bearing material and the shaft together. Therefore, it is possible to investigate different bearing and shaft materials and the effects of heat treatments on these materials. Such a mechanism provides wear of bearings rather than using standard methods as this is more appropriate direct [22].

The system is formed by a weight applied by a rigid bar, a steel bar connected to the bearing from a distance and a comparator. Friction coefficient is determined from the friction force formed along the rotating direction of the bearing and from the movement of the steel bar connected to the bearing [23]. Radial wear test rig is illustrated in Fig. 1.

In the experiments under lubricated conditions, very little movement was taken place for high comparator's spring coefficient and low friction. Therefore, a tensile spring of $k = 0.004$ N/mm has been connected on the opposite side of to the comparator. The movements formed by the effect of the friction force have been measured by this method.

3. Results and discussion

3.1. Surface roughness properties

Values of surface roughness before and after wearing process were shown in Table 2. These values of surface roughness CuSn10, CuZn30 and pure Sn decreased and the other pure Cu and pure Zn bearings increased after wear tests because of soft phase properties. These tests were performed on Mitutoyo-CE surface roughness test rig. Hardness of these bearing specimens was found to be around 100 HB. Results of mechanical tests were given in Table 3.

3.2. Wear properties

Friction coefficient, bearing temperature, bearing and journal wear loss values are given in Figs. 2–6. The friction coefficient–time variation of bearings is shown in Fig. 2. The temperature–time variation of bearings is given in Fig. 3. The wear losses of bearing–time variation of bearings are shown in Fig. 4. The wear losses of journal–time variation of bearings are shown in Fig. 5. The wear rate values of bearings depending on materials are shown in Fig. 6. Friction coefficient was determined as a function of normal and friction force. The highest friction coefficients occurred in CuSn10 and pure Cu bearings whereas the lowest friction coefficients occurred in pure Sn and pure Zn, bearings. The highest bearing temperatures occurred in CuSn10 and CuZn30 bearings whereas the lowest bear-

Table 2
Roughness of bearing materials.

Roughness (μm)	SAE 1050	CuSn10	CuZn30	Pure Cu	Pure Sn	Pure Zn
Before wear	0.5	1.61	2.5	0.45	1.35	1.25
After wear	0.3	1.03	1.85	0.68	0.96	1.52

Table 3
Mechanical properties of bearing materials.

Materials	Yield strength $R_{p0.2}$ (MPa)	Tensile strength $\sigma_ç$ (MPa)	Break strength σ_k (MPa)	Elongation % ε	Compressive strength σ_b (MPa)	Notch impact strength (J)	Bending angle α°	Hardness (HB)	Radial fracture strength σ_{rk} (MPa)
CuSn10	260	370	280	16	1200	16	125	100	83
CuZn30	450	500	480	16	1000	14	140	120	105
Cu	150	200	160	23	800	185	120	70	156
Sn	30	35	35	10	150	1	90	15	1
Zn	38	40	40	1.5	400	3.5	180	35	8

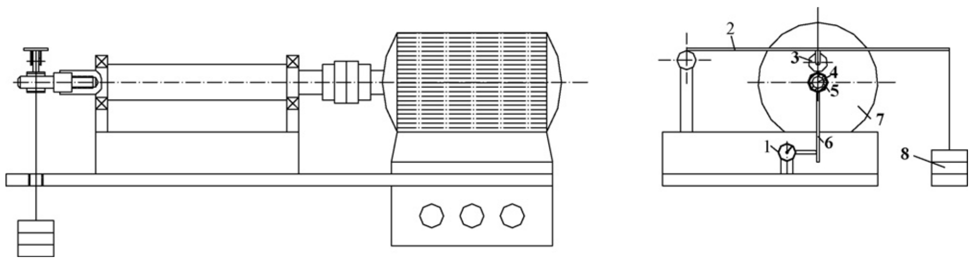

Fig. 1. Radial journal bearing wear test rig: (1) comparator, (2) rigid bar, (3) load contact point (rolling bearing), (4) journal sample, (5) journal bearing samples, (6) plate bar, (7) motor, and (8) loads.

ing temperatures occurred in pure Cu, pure Sn and pure Zn bearings. The highest wear loss occurred in CuZn30 and CuZn30 bearings, whereas the lowest wear loss occurred in pure Zn, Pure Cu and pure Sn bearings. The highest journal wear loss occurred in Pure Cu bearings, whereas the lowest journal wear loss occurred in CuSn10 and pure Zn bearing. The highest bearing wear rate occurred in CuSn10 and CuZn30 bearings, while the lowest bearing wear rate occurred in pure Zn bearing.

From these bearings, friction coefficients for CuSn10 and pure Cu was 0.1, CuZn30 was 0.06, pure Sn was 0.02, and pure Zn was 0.01 in 2.5 h. Bearing temperatures for CuZn30 was 55 °C, CuSn10 was 50 °C, pure Cu was 43 °C, and pure Zn was 40 °C, and pure Sn was 38 °C in 2.5 h. Bearing wear loss for CuSn10 and CuZn30 was 12 mg, pure Sn was 4 mg, pure Cu was 3 mg, and pure Zn was 1 mg in 2.5 h. Journal wear loss for pure Cu was 9 mg, CuZn30 was 5 mg, pure Sn was 4.5 mg, CuSn10 and pure Zn was about 2 mg. Bearing wear rate of CuSn10, and CuZn30 was 10×10^{-6} mm^3/N m, pure Sn was 6.5×10^{-6} mm^3/N m, pure Cu was 3×10^{-6} mm^3/N m, whereas that for pure Zn bearings was 1×10^{-6} mm^3/N m.

Friction coefficient and bearing temperature of alloyed bearings were generally higher than those of pure bearings. Alloyed CuZn30 bearing had higher wear than that of alloyed CuSn10 bearing. But, wear in CuZn30 bearing was higher than that of in CuSn10 bearing. In addition, bearing wear loss values of pure Cu, pure Sn, and pure Zn bearings were lower than those of other alloyed bearings. Nevertheless, use of pure Cu in bearing material is limited because

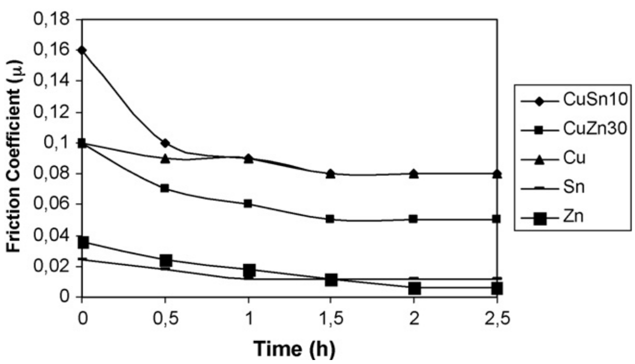

Fig. 2. The friction coefficient–time variation of bearings.

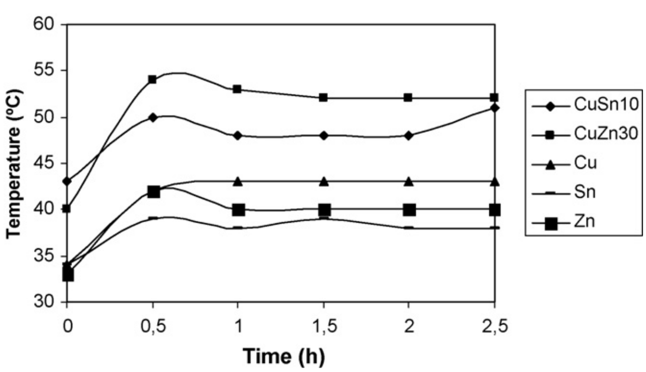

Fig. 3. The temperature–time variation of bearings.

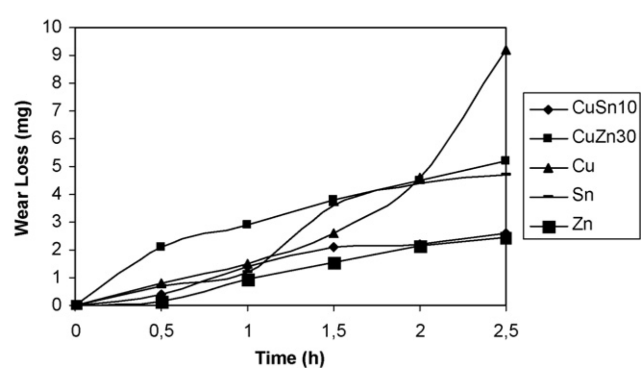

Fig. 5. The wear losses journal–time variation of bearings.

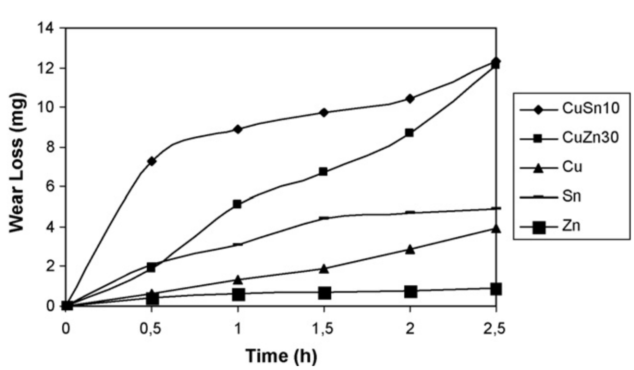

Fig. 4. The wear losses bearing–time variation of bearings.

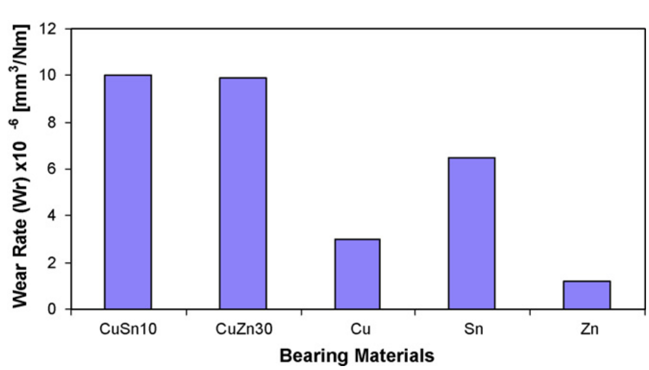

Fig. 6. The compare of wear rates of bearing materials.

pure Cu has poor mechanical properties and causes higher wear in journal. As a result, usage of alloyed bearings is more suitable as bearing material.

In our previous study [24], we determined that friction coefficient, bearing temperature, and wear losses increased depending on *pv* (load and velocity) parameters in bronze bearings. These parameters were 0.0125, 0.025, and 0.05 N/mm s. Friction coefficient values were found to be 0.05–0.1, bearing temperature values were found to be 40–50 °C, and of wear loss values were found to be 3–15 mg on lubricated conditions at 2.5 h sliding time.

Coupard et al. [25] has determined the friction coefficient as approximately 0.7 at AISI-54100 steel against to CuSn12 bronze on pin-on-disc at 5 N load, 235 mm/s velocity and 30 min. In addition, friction coefficient and weight loss of bronze specimens are found to increase linearly when increasing the sliding velocity and load [25,26]. Sharma et al. [27] determined that high speed or high load affects the wear rate in journal bearings. Rapoport et al. [28] and Gronostajski et al. [21] determined the friction coefficient of 0.08 in bronze bearings.

Rivas et al. [29] determined the friction coefficient of approximately 0.073, wear loss of 1.76 mg in SAE 67 bronze (15% Pb, 7% Sn) bearings at 0.13 m/s sliding speed and 814 N loads. Türk et al. [30] determined the friction coefficient of approximately 0.25, wear loss of 25 mg/km in SAE 660 bronze bearings at 0.5 m/s sliding speed and 30 N loads.

Savaşkan et al. [12], and Pürçek et al. [13] investigated tribological properties of Zn–Al based and SAE 660 bronze (7% Pb, 7% Sn, 3% Zn) journal bearings. They determined the friction coefficient as approximately 0.04, wear loss of 0.5 mm^3 in bronze bearings at 1.3 m/s sliding speed and 20 MPa pressure. Savaşkan and Azaklı [31] determined the friction coefficient of approximately 0.05, wear loss of 0.1 mm^3 in SAE 65 bronze (CuSn12) bearings at 0.79 m/s sliding speed, and 1 MPa pressure.

Elleuch et al. [32] determined the friction coefficient of 0.05, wear rate of 10 mg in SAE 619 brass Zeren [33] and Feyzullahoğlu et al. [34] determined the friction coefficient of approximately 0.05, wear rate of 10 mg in SAE 619 brass (2.4% Pb, 0.2% Sn, 39.5% Zn) and friction coefficient of approximately 0.06, wear rate of 20 mg in WM-2 (89% Sn, 7.2% Sb, 3% Cu) bearings at 1500 rpm sliding speed

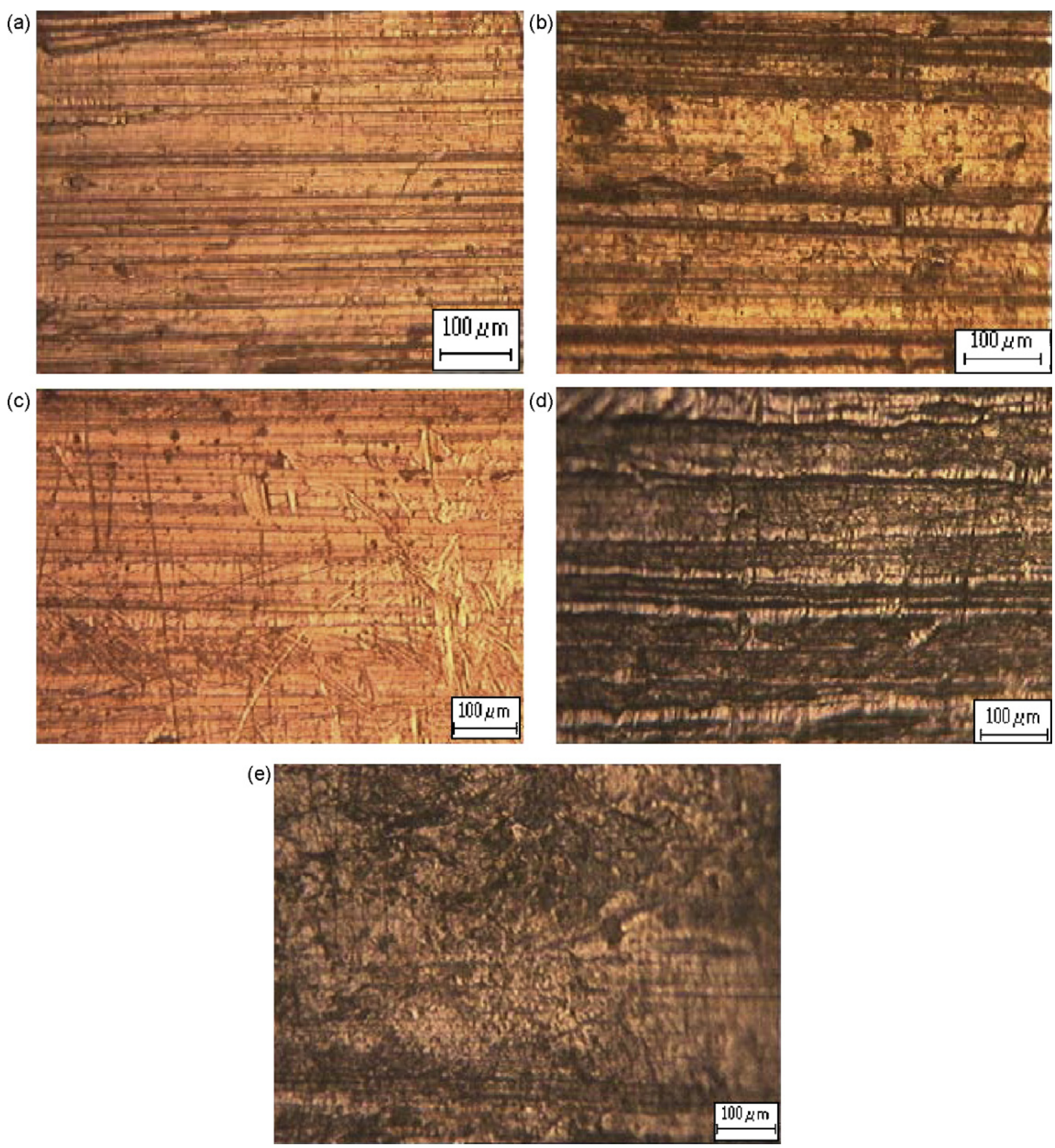

Fig. 7. Microstructure of wear surfaces of bearings: (a) CuSn10, (b) CuZn30, (c) Cu, (d) Sn, and (e) Zn (100×).

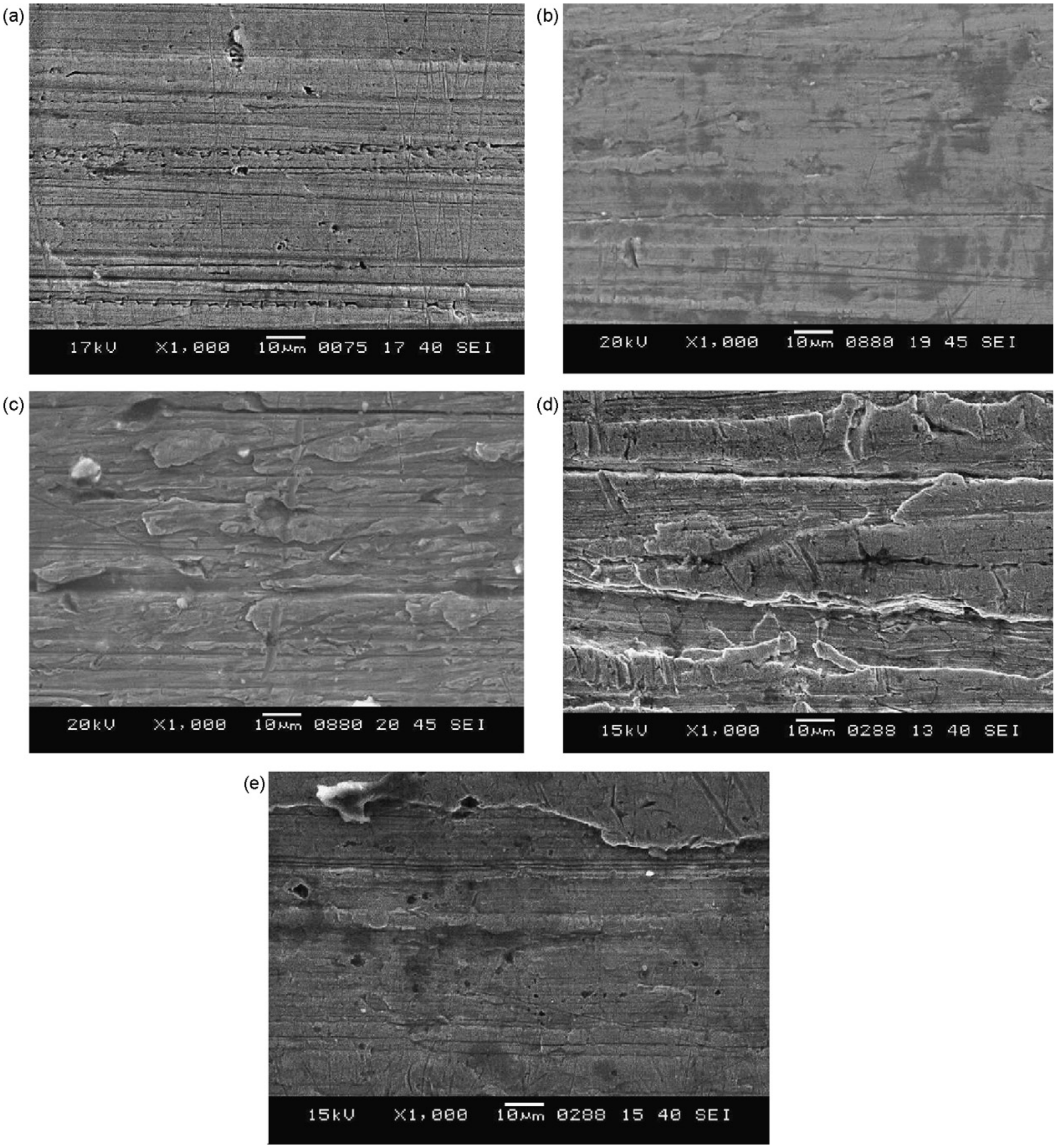

Fig. 8. SEM microstructure of wear surface of bearings: (a) CuSn10, (b) CuZn30, (c) Cu, (d) Sn, and (e) Zn (1000×).

and 115 N loads, on dry and lubricated conditions. They reported that Sn element increased embability of bronze, brass, and Sn based bearings. In addition, they reported that these alloys could be used in industry applications by adding different alloy elements.

The differences in our results and those of other previous studies may be attributed to the fact that their materials were different from our materials and test conditions. In addition, our results show that radial journal bearing test rig gives more accurate measurements.

3.3. Mechanical properties

Mechanical properties of copper based bronze, and brass bearing materials generally occurred than those of pure bearing materials (Table 3). The highest mechanical properties occurred in CuSn10 and CuZn30 bearing materials whereas the lowest mechanical properties occurred in pure Sn and pure Zn bearing materials. In addition, although notch impact and radial fracture strength of pure Cu bearing materials are higher than those of according to the other bearing materials; compressive strength, hardness and the other mechanical properties are lower. Mechanical properties of the other pure Sn and pure Zn bearing materials are lower than those of alloyed bearings.

3.4. Microstructure properties

The wear surfaces in the specimens were examined using the optical (Hund Wetzlar CCD-290) and scanning electron microscope (Jeol JSM-6060). Microstructures of wear surface of bearings are presented in Fig. 7. SEM microstructures of wear surfaces of bear-

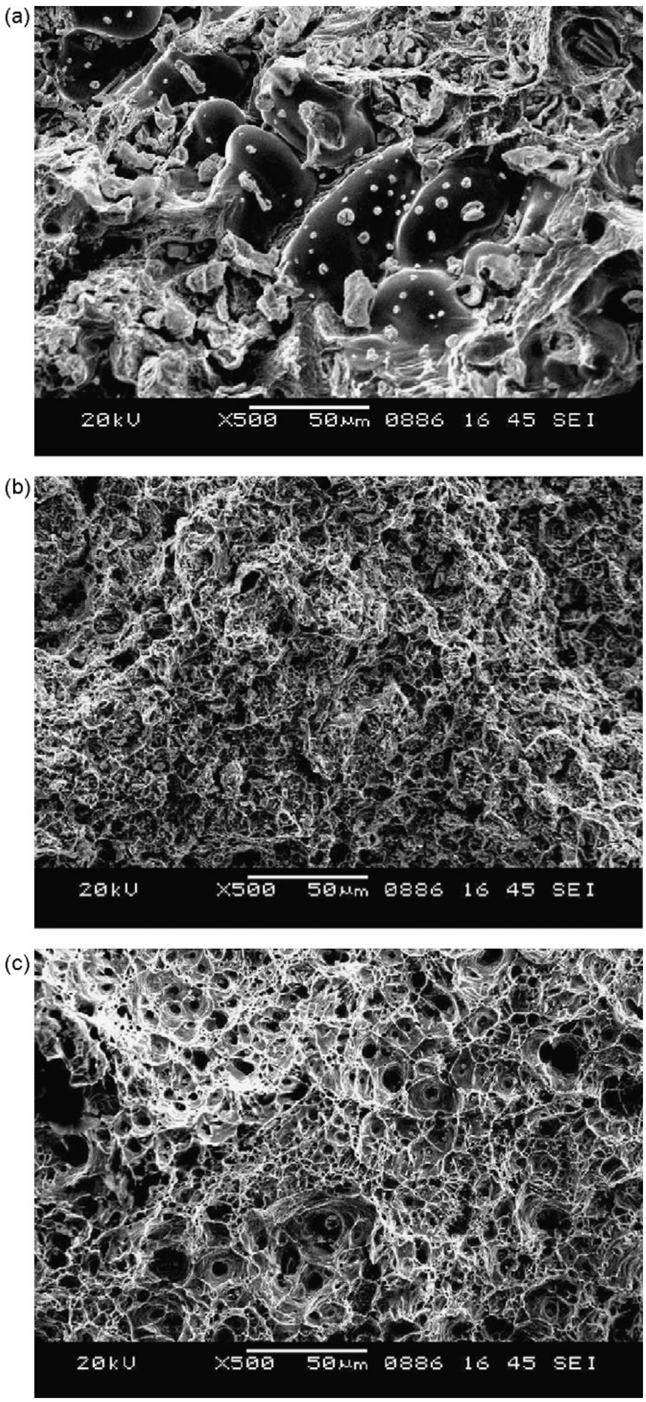

Fig. 9. SEM microstructure of tensile fracture surface of bearing materials: (a) CuSn10, (b) CuZn30, (c) Cu (500×).

ings are shown in Fig. 8. Homogeneous and small wear tracks were present in bronze bearing, and big wear tracks occurred in brass bearing. Homogeneous wear tracks and adhering occurred in pure Cu, Sn, and Zn bearings due to soft phases. Wear tracks occurred local moving and friction direction were apparent in bearings (Figs. 7–8a–d).

Prasad [26] have observed microcracks, debris and limited damage on surfaces of bronze materials. Savaşkan et al. [12], Pürçek et al. [13], and Savaşkan and Azaklı [31] have observed deep scratches, smearing, and abrasive wear tracks on surfaces of bronze bearings. Rivas et al. [29] have observed adhesive junctions in interface of bronze bearings. They reported that good wear performance of bearing was obtained because lead acts as an additional lubricant. Elleuch et al. [32] have observed delamination and wear tracks on surfaces of brass bearings. Zeren [33] and Feyzullahoğlu et al. [34] have observed embability of Sn element. They reported that two phases (Zinc and copper) in brass bearings. In this study, similar wear tracks were obtained at lubricated conditions.

SEM microstructure of tensile fracture surfaces of bearing materials are shown in Fig. 9. As can be seen in tensile fracture surfaces, in bronze, and brass bearing materials fractures occurred as thinly grained pure Cu bearing materials had thick fractures (Fig. 9). SEM microstructure of tensile fracture surfaces of pure Sn, and pure Zn bearing materials were not examined because of soft materials and low mechanical properties.

4. Conclusions

We conclude that journal bearings manufactured from metal based materials may be effectively used in the industry due to better tribological and mechanical properties. In this study, tribological and mechanical properties of journal bearings manufactured by copper based CuSn10, CuZn30 and pure Cu, Sn and Zn were investigated. The following conclusions can be drawn:

1. Post-wear values of surface roughness decreased in CuSn10, CuZn30 and pure Sn, but these values increased in the other pure Cu and pure Zn bearings.
2. The highest friction coefficients occurred in CuSn10 and pure Cu bearings whereas the lowest friction coefficients occurred in pure Sn and pure Zn, bearings.
3. The highest bearing temperatures occurred in CuSn10 and CuZn30 bearings whereas the lowest bearing temperatures occurred in pure Cu, pure Sn and pure Zn bearings.
4. The highest wear loss occurred in CuZn30 and CuZn30 bearings, whereas the lowest wear loss occurred in pure Zn, Pure Cu and pure Sn bearings. The highest journal wear loss occurred in Pure Cu bearings, whereas the lowest journal wear loss occurred in CuSn10 and pure Zn bearing. The highest bearing wear rate occurred in CuSn10 and CuZn30 bearings, while the lowest bearing wear rate occurred in pure Zn bearing.
5. The highest mechanical properties occurred in CuSn10 and CuZn30 bearing materials whereas the lowest mechanical properties occurred in pure Sn and pure Zn bearing materials.
6. Homogeneous and small wear tracks were present in bronze bearing, and big wear tracks occurred in brass bearing. Homogeneous wear tracks and adhering occurred in pure Cu, Sn, and Zn bearings.
7. In bronze and brass bearing materials fractures were occurred as thick grained, whereas in pure Cu bearing material was occurred as thin grained.

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