Role of Zinc on Physical Properties of Sn-Sb-Cu Rapidly Solidified From Melt

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Abstract: Structure, electrical resistivity, hardness, elastic modulus and roughness of Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%]. Rapidly solidified alloys have been investigated. Investigations have been made by using X-ray diffract meter, double bridge, Vickers hardness tester, the dynamic resonance technique and surface roughness tester. X-ray diffraction showed that, adding different amounts of zinc to the Sn-10%Sb-2%Cu changed its structural properties which affect all measured physical properties. Elastic modulus, hardness and electrical resistivity are increased by increasing the zinc content. Internal friction and roughness are varied. Our results showed that the Sn-10%Sb-2%Cu-1%Zn has better properties for bearing applications.

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Key words: Bearing alloys, X-ray, electrical resistivity, mechanical properties

1. Introduction

Sn–Sb–Cu alloy alloys are widely used in journal bearings as Babbitts. The microstructure of these alloys consists of a soft solid solution matrix and two intermetallic compounds (CuSn, SbSn) that are harder than the matrix. This specific microstructure qualifies these alloys as bearing materials [1]. Babbitts are either tin or lead-based alloys having excellent embed ability and conformability characteristics. Despite their higher cost, tin babitts are often used in preference to lead babitts due to their excellent corrosion resistance, easy bonding and less tendency towards segregation [2]. Tin base Babbitts commonly contain antimony and copper [3]. They have adequate hardness number which gives them excellent load-carrying characteristic. They show low friction resistance, low wear, good run-in properties and good emergency behavior in the absence of adequate lubrication. They "wet" easily and maintain an oil film, resist corrosion, are easily cast and bonded and retain good mechanical properties at elevated temperatures. Furthermore, the quantities of antimony and copper cannot be increased, since high concentrations of antimony causes multiple agglutinations of the SbSn crystals in the matrix and cupper constitute a hard intermediate layer, which does not possess sufficient toughness and leads to binding defects. Hence a limitation of antimony to 12 percent and of copper to 6 percent has proved appropriate. Ishihara et al [4] studied effect of the amount of antimony on sliding wear resistance of white metal. Their results showed that the sliding wear resistance is not affected by the amount of antimony within a range 5–18 wt%, however the resistance is lowered at the higher amount of antimony.

It is usual to improve the mechanical properties of bearing metals by adding further alloying elements such as zinc. Kamal et al [5] mentioned that the micro additions of zinc cause a marked change in the growth morphology of SnSb cuboidal particles. Only in larger quantities of zinc could cause a microstructure-refining effect, which becomes more marked with increasing content. The refining refers to both the SbSn precipitations and the CuSn precipitations. Together with the mixed-crystal hardening, this has a positive effect on the mechanical properties. The cooling rate affects the mechanical properties, Goudarzi et al [1] studied the effect of solidification rate and heating on microstructure and hardness of tin based white metals. Their results showed that the rapid cooling suppresses formation and growth of SbSn cuboids and increases hardness. Sn-based alloys are used in some delicate soldering for electronic equipments; they are also used in computer and other fields of industry. More knowledge about their mechanical properties may be helpful in industrial applications. Therefore, this study aims to investigate the effect of zinc addition on the rapidly solidified Sn-Sb-Cu alloys.

2. Experimental work

The samples used in the present work are Sn-10Sb-2Cu-XZn (X=0.5, 1.0, 1.5, 2.0, and 2.5wt%] were melted in a muffle furnace using tin, antimony, copper and zinc of purity better than 99.5 %. The resulting ingots were turned and re-melted four times to increase the homogeneity. From these ingots, long ribbons of about 4 mm width and ~70 µm thickness were prepared by a single roller method in air (melt spinning technique). The surface velocity of the roller was 31.4 m/s giving a cooling rate of ~3.7 × 105 K/s.

The samples then cut into convenient shape for the measurements using double knife cuter. The internal friction Q^{-1} and the elastic constants of used alloys were determined using the dynamic resonance method. The value of the dynamic Young modulus E is determined by the following relationship [6–8]:

$$\left(\frac{E}{\rho}\right)^{1/2} = \frac{2\pi L^2 f_0}{kz^2}$$

Where ρ the density of the sample under test, L the length of the vibrated part of the sample, k the radius of gyration of cross section perpendicular to its plane of motion, f_0 the resonance frequency and z the constant depends on the mode of vibration and is equal to 1.8751. Plotting the amplitude of vibration against the frequency of vibration around the resonance f_0 gives the resonance curve, the internal friction, Q^{-1}, of the sample can be determined from the following relationship:

$$Q^{-1} = 0.5773\frac{\Delta f}{f_0}$$

Where Δf the half width of the resonance curve.

Vickers hardness number at loads 10 gf, with constant indentation time, 5 sec, of used alloys was measured using Vickers micro-hardness tester (Model - FM- 7- Japan). X-ray analysis has been measured using the convention powder diffraction techniques. The roughness of the samples have been done using (Surface roughness tester, Surf test SJ201P).

Figure (1a)

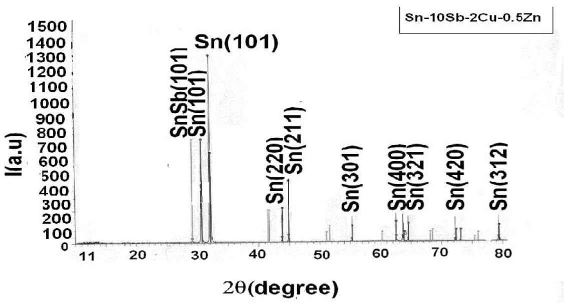


Figure (1b)

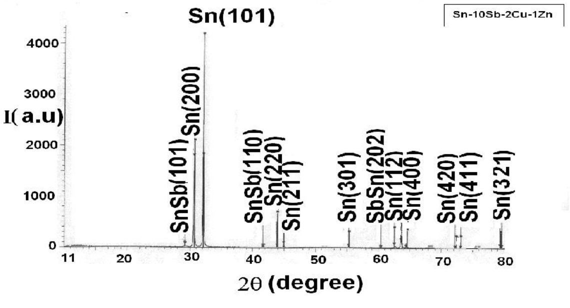


Figure (1c)

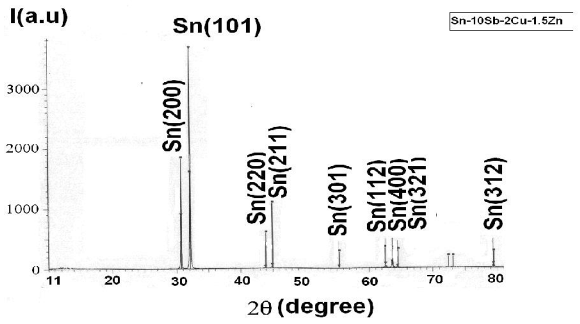


Figure (1d)

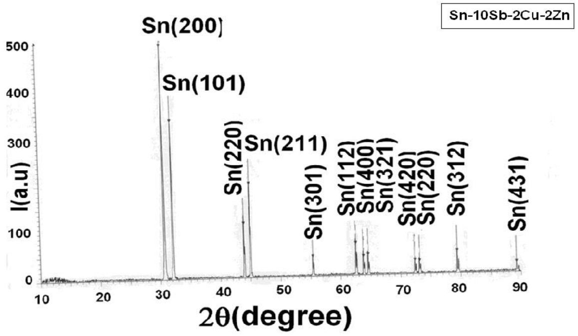


Figure (1f)

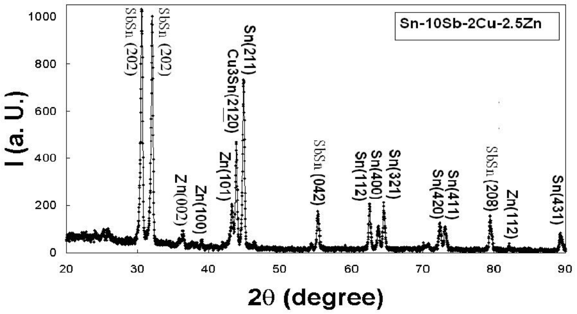


Figure 1. X-ray diffraction patterns for Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys

3. Results and Discussion

X-Ray Measurements

The peaks of the X-ray diffraction patterns given in Fig. 1, which cover the range from 20◦ to 90◦ indicate that the diffracted X-rays come from ordered atomic orientations arranged in numerous sets of parallel planes in the crystal [9]. X-ray diffraction showed that, adding different amounts of zinc to the Sn-10%Sb-2%Cu alloy changed its structural properties which affect all measured physical properties .X-ray diffraction patterns, Fig. 1, and its analysis show that, the Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%]alloys have body central tetragonal of tin phase, matrix, with different inter-metallic compounds, SnSb/or SbSn and Cu3Sn in, imbedded in the matrix depending on the alloy composition. X-ray patterns (Fig.1 f)) show that new hexagonal Cu3Sn and Zn phases are formed with a change in the internal structure of the Sn–Sb matrix as given by the crystal size, position and intensity of these phases.Cu3Sn and Zn didn't appear in the other alloys this is due to the low zinc and cupper contents in these alloys.

The lattice parameters a, c, c/a ratio and the volume of unit cell of Sn matrix are almost constants for zinc additions 0.5, 1, 1.5 and 2.0 wt%. The lattice parameter a decreased whereas c increased for 2.5 % zinc contents this elongation in the tetragonal unit cell may be due to the presence of the hard inclusion compound Cu3Sn in the soft Sn matrix in this alloy. Accordingly the volume of the unit cell was varied as shown in table 1.

Table 1. The lattice parameters a, c, c/a ratio and the volume of unit cell of Sn matrix for Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys.

Sample	a (Å)	c (Å)	c/a	V (a^2.c) (Å^3)
Sn-10Sb-2Cu-0.5Zn	5.832	3.034	0.520	103.170
Sn-10Sb-2Cu-1Zn	5.839	3.590	0.615	122.430
Sn-10Sb-2Cu-1.5Zn	5.838	3.240	0.555	110.436
Sn-10Sb-2Cu-2Zn	5.823	3.174	0.545	107.628
Sn-10Sb-2Cu-2.5Zn	4.540	4.275	1.060	88.114

The electrical receptivity and temperature coefficients of the resistivity for the Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys are varied as shown in table (2). This is because their internal structure changes decrease or increase the crystal size of the phases and increase or decrease their quantity with change in their positions, as seen in X-ray patterns and their analysis.

Table 2. The electrical receptivity and temperature coefficients of the resistivity for the Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys.

Alloy	Resistivity at room temperature(μΩ.cm)	T.C.R(k^{-1})
Sn-10Sb-2Cu-0.5Zn	54.820±2.300	0.100
Sn-10Sb-2Cu-1Zn	57.432±3.089	0.002
Sn-10Sb-2Cu-1.5Zn	60.023±4.920	0.005
Sn-10Sb-2Cu-2Zn	80.543±1.069	0.006
Sn-10Sb-2Cu-2.5Zn	77.823±1.069	0.010

Figure (2a) shows the variation of the electrical resistivity of the Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%]alloys versus temperature, from this figure the Sn-10%Sb-2%Cu-1.5%Zn has better properties for bearing applications it can be used as a solder alloy. Also figure (2b) temperature coefficient of resistivity of the Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys is varied, which is sensitive to micro-structural changing, depending on the alloy composition.

The alloying elements dissolved or formed new phases which caused a variation in the values of internal friction, elastic constants (elastic modulus, bulk modulus, Shear modulus as in table 3). The elastic modulus and internal friction values of Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0 and 2.5 wt%] alloys are shown in figures (3a) and (3b). From these figure it obvious that, the elastic modulus and internal friction values of these alloys are varied which is depending on its alloys composition, increasing the amount of zinc content to Sn-10%Sb-2%Cu alloy.

Again the highest elastic modulus was obtained for the alloy containing 2.5 wt%, this was due to the formation of phases Zn and also Cu_3Sn, according to the surface activity theory [10], Zn and Cu atoms in Sn matrix migrate towards grain boundaries thus limiting their mobility and inhibit grain growth. The presence of Zn and Cu in Sn matrix allow the formation of the intermediate compound of Cu_3Sn which reduce the effect of Cu atoms on the mobility of grain boundaries in SnZnCu samples and produce larger grains during sample preparation.

The Vickers hardness value of Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys (table 4) is increased by increasing the amount of zinc to Sn-10%Sb-2%Cu alloy (as in figure 4), because these dissolved atoms and their inter-metallic compounds act as hard inclusions in the matrix, giving more strength, hence increasing its hardness value (table 4).

Fig.(2a)

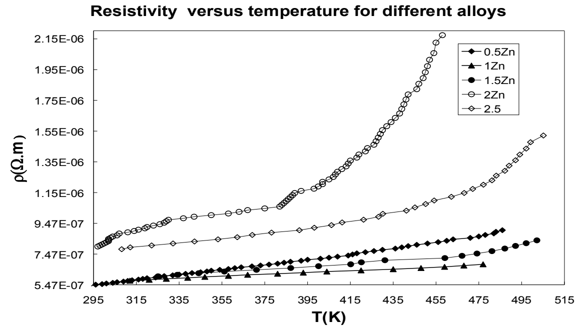


Figure (2a). The variation of the electrical resistivity of the Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys versus temperature.

Fig.(2b)

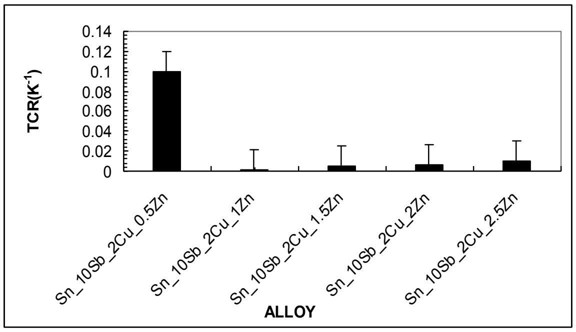
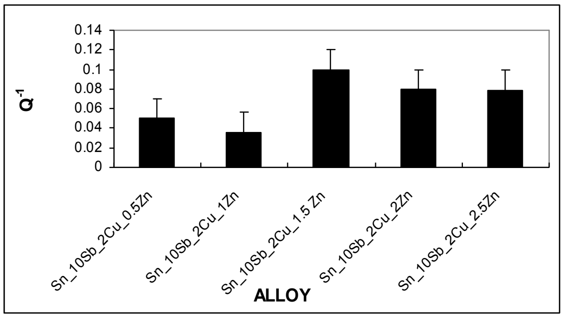


Figure (2b). The temperature coefficient of resistivity of the Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys

Table 3. The elastic moduli and internal friction values of Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0 and 2.5 wt%] alloys.

ALLOY	Internal Friction (Q^{-1}))	Elastic modulus (GPa)	Bulk Modulus (GPa)	Shear Modulus (GPa)
Sn-10Sb-2Cu-0.5Zn	0.050 ±0.015	16.700±1.460	19.800±1.700	9.900±0.730
Sn-10Sb-2Cu-1Zn	0.036 ±0.010	26.260 ±1.478	28.580±4.480	6.137±0.648
Sn-10Sb-2Cu-1.5 Zn	0.100±0.020	28.122±9.400	32.260±2.040	10.355±0.640
Sn-10Sb-2Cu-2Zn	0.082±0.020	24.459±4.470	27.960±5.500	8.999±1.640
Sn-10Sb-2Cu-2.5Zn	0.079±0.020	32.700±3.350	50.700±3.480	11.700±1.069

Figure(3a)



Figure(3b)

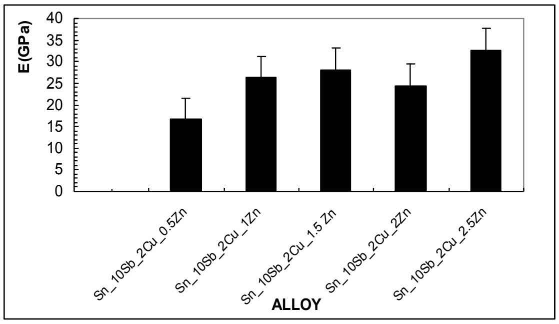


Figure 3. The internal friction values (figure (3a)) and the elastic modulus (figure (3b)) of Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0 and 2.5 wt%] alloys.

Table 4. The Vickers hardness values of Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys.

Alloy	Hv(gf/mm^2)
Sn_10Sb_2Cu_0.5Zn	16.64
Sn_10Sb_2Cu_1Zn	25.45
Sn_10Sb_2Cu_1.5Zn	33.2
Sn_10Sb_2Cu_2Zn	34.4
Sn_10Sb_2Cu_2.5Zn	37.32

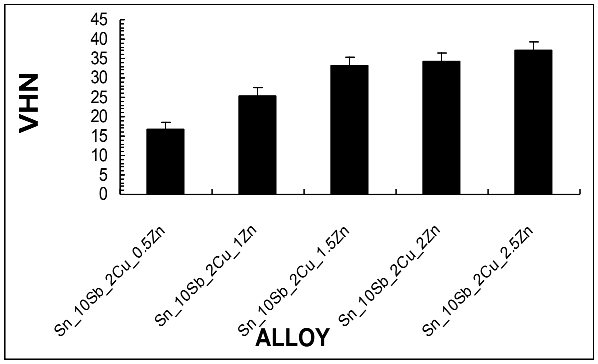


Figure 4. The Vickers hardness values of Sn-10%Sb-2%Cu-xZn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys.

Surface roughness

The roughness is an important for bearing materials. The roughened crankshaft may in turn cause wear of the bearings. Not only roughness of the surface but also dirt entering the bearing clearance with the oil flow is a source of bearing damage [11]. Relatively large particles on the roughness surface which may be left in crankshaft drilling such as that, bearing materials is displaced around the particle and appears as a ring of alloy producing from the bearing surface. This ring is rubbed by the crankshaft. But again the presence of soft, low melting point phase prevents the local welding or pick up of bearing alloy on the crankshaft and avoids seizure [12]

Roughness measurements have been done using Surface roughness tester, Surftest SJ201P. The surface roughness parameters (Average roughness height, Ra, Ten-point height, Rz, Root mean square roughness, Rq Maximum peak to valley height, Rt and Maximum height, Rp) for Sn-10%Sb-2%Cu-xZn [1.0, 1.5 and 2.0 wt%] alloys are shown in table 5. According to table 5 the alloy with 1.5 Zn content has smoothest surface and is good for bearing applications.

Table 5. The surface roughness parameters (Average roughness height, Ra, Ten-point height, Rz, Root mean square roughness, Rq Maximum peak to valley height, Rt and Maximum height, Rp) for Sn-10%Sb-2%Cu-xZn [1.0, 1.5 and 2.0 wt%] alloys.

Alloy	R_a(μm)	R_z(μm)	R_q(μm)	R_t(μm)	R_P(μm)
Sn_10Sb_2Cu_1Zn	0.587	3.375	0.920	6.170	1.225
Sn_10Sb_2Cu_1.5Zn	0.587	2.134	0.478	2.776	0.866
Sn_10Sb_2Cu_2Zn	0.386	3.106	0.645	6.283	0.700

Conclusion

The present paper investigated the Structure, electrical resistivity, hardness, elastic modulus and roughness of Sn-10%Sb-2%Cu-x%Zn [x = 0.5, 1.0, 1.5, 2.0, 2.5 wt%] alloys. The x-ray measurements showed a changing in the structure of the matrix due to the formation of intermetallic compounds SbSn and/or SnSb and Cu3Sn and formation of the hexagonal closed packed structure of Zn. The electrical resistivity increased with increasing Zn in the samples due that these intermetallic compounds act as scattering centers for the electrical current. The alloy with 2.5 wt% Zn content has the most improved properties between the others.

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