



Corrosion behavior and physical properties of modified tin- anti-mony bearing alloy

Abu Bakr El- Bediwi, Abbas Al- Bawee*, Mustafa Kamal

Metal Physics Lab., Physics Department, Faculty of Science, Mansoura University, Mansoura, (EGYPT)
Faculty of engineering, University of Diayala, (IRAQ)

ABSTRACT

Effect of adding alloying elements, such as Cu, Bi, Al, Pb, Zn and Ag, on microstructure, corrosion behavior, electrical, thermal and mechanical properties of SnSb₁₃ alloy have been investigated. Matrix microstructure, formed phases and other lattice parameters, of SnSb₁₃ alloy changed after adding alloying elements which effects on all measured physical properties. Corrosion parameters, elastic modulus, internal friction, Vickers hardness, electrical resistivity and thermal parameters of SnSb₁₃ alloy varied after adding alloying element. The Sn₈₇Sb₁₀Bi₃ alloy has lowest corrosion rate but Sn₈₇Sb₁₀Al₃ alloy has highest corrosion rate. The Sn₈₇Sb₁₀Pb₃ alloy has best bearing properties, lower internal friction, self-lubricate and cost, adequate hardness, corrosion resistance, elastic and thermal properties, for automotive applications. © 2015 Trade Science Inc. - INDIA

KEYWORDS

White bearing;
Microstructure;
Thermo-elastic properties;
Internal friction;
Corrosion behavior.

INTRODUCTION

Bearing is a device used to transmit loads between relatively moving surfaces or in another word is a device to allow constrained relative motion between two or more parts, typically rotation or linear movement. There is many ways for classifying bearing materials, for example, by the type of material they making up off or by the applications they service. Effects of modification structural on electrical resistivity, elastic modulus, internal friction and hardness of SnSb₁₀Cu₂X₂ (X= Pb, Zn, Se, Ag and Cd) has been investigated^[1]. The SnSb₁₀Cu₂Pb₂ alloy has better properties for bearing applications. Adding Cu/Pb to Sn-Sb alloy improve their elastic modulus, internal friction, hardness and thermal con-

ductivity^[2]. The friction coefficients of WM5, (Sn–20.2%Sb–16.6%Pb–2.6%Cu), are lower than that of WM2, (Sn–7.2%Sb–0.4%Pb–3%Cu), under all scratch test conditions^[3]. Structure, hardness, mechanical and electrical transport properties of (90-x) Sn10%SbX%Bi (x = 0, or x e'1) alloys have been studied and analyzed^[4]. Effects of solidification rate, microadditions and heating on mechanical properties and micromorphology of Sn- 10.4% Sb alloy have been studied^[5, 6]. Creep behaviour, elastic modulus and internal friction of Sn 10%Sb 2%Cu 2%X (X=Pb, Ag, Se, Cd and Zn) alloys have been investigated and stress exponent values have been determined using Mulhearn–Tabor method^[6]. The directionally solidified microstructure of Sn-16%Sb hyperperitectic alloy has been investigated at vari-

ous solidification rates using a high-thermal gradient directional solidification apparatus^[7]. The aim of this research was to study and analyze the effect of copper, lead, silver, bismuth, aluminum and zinc on corrosion behavior and physical properties of SnSb₁₃ white bearing.

EXPERIMENTAL WORK

In this work SnSb_{13-x}X_x (X=Bi, Cu, Al, Pb, Zn and Ag & x=3 wt.%) alloys were molten in the muffle furnace using high purity, more than 99.95%, tin, antimony, bismuth, lead, zinc, copper, aluminum and silver. The resulting ingots were turned and remelted several times to increase the homogeneity of the ingots. From these ingots, long ribbons of about 3-5 mm width and ~ 70 μm thickness were prepared as the test samples by directing a stream of molten alloy onto the outer surface of rapidly revolving copper roller with surface velocity 31 m/s giving a cooling rate of 3.7×10^5 K/s. The samples then cut into convenient shape for the measurements using double knife cutter. Structure of used alloys was performed using an Shimadzu X-ray Diffractometer (Dx-30, Japan) of Cu-Kα radiation with $\lambda=1.54056 \text{ \AA}$ at 45 kV and 35 mA and Ni-filter in the angular range 2θ ranging from 0 to 100° in continuous mode with a scan speed 5 deg/min. Also Scanning electron microscope JEOL JSM-6510LV, Japan was used to study structure. Electrical resistivity of used alloys was measured by a conventional double bridge method. The melting endotherms of used alloys were obtained using a SDT Q600 V20.9 Build 20 instrument. A digital Vickers micro-hardness tester, (Model-FM-7- Japan), was used to measure Vickers hardness values of used alloys. Internal friction Q⁻¹ and the elastic constants of used alloys were determined using the dynamic resonance method^[8-10].

RESULTS AND DISCUSSIONS

Structure

X-ray diffraction patterns of SnSb_{13-x}X_x (X=Bi, Cu, Al, Pb, Zn, Ag and x=3 wt. %) rapidly solidified alloys have lines corresponding to β- Sn and

SbSn intermetallic phases as shown in Figure 1. The analysis of x-ray diffraction patterns show that, adding copper, lead, silver, bismuth, aluminum and zinc to Sn₈₇Sb₁₃ alloy caused a change in matrix microstructure such as lattice parameters and formed crystal structure (crystallinity, crystal size and the orientation). Lattice parameters, (a and c), and unit volume cell of β- Sn phase in SnSb_{13-x}X_x alloys were determined and then listed in TABLE (1). Lattice parameters of β- Sn in Sn₈₇Sb₁₃ varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. That is because Bi, Cu, Al, Pb, Zn and Ag atoms dissolved in Sn matrix alloy forming a solid solution and other accumulated atoms forming traces of phases.

Scanning electron micrographs, SEM, of SnSb_{13-x}X_x (X=Bi, Cu, Al, Pb, Zn and Ag & x=3 wt. %) alloys show heterogeneity structure, different phases with other soluble atoms, as shown in Figure (2). Microstructure of SnSb_{13-x}X_x alloys show β- Sn matrix, SbSn phase and other accumulated atoms forming traces of phases and that agree with x-ray results.

Thermal properties

Thermal analysis is often used to study solid state transformations as well as solid-liquid reactions. Figure (3) shows DSC thermographs for SnSb_{13-x}X_x (X=Bi, Cu, Al, Pb, Zn, Ag and x=3 wt. %) alloys. Little variation in exothermal peak of SnSb₁₃ alloy occurred, which related to a change in Sn matrix structure, after adding Bi, Cu, Al, Pb, Zn and Ag contents. The melting temperature and other thermal properties of SnSb_{13-x}X_x alloys are listed in TABLE (2). Melting temperature of SnSb₁₃ alloy decreased after adding Bi, Cu, Al, Pb, Zn and Ag contents.

Elastic moduli and internal friction

The elastic constants are directly related to atomic bonding and structure. Elastic moduli of SnSb_{13-x}X_x alloys are listed in TABLE (3). Elastic modulus of SnSb₁₃ alloy varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. The Sn₈₇Sb₁₀Zn₃ alloy has highest elastic modulus but Sn₈₇Sb₁₀Al₃ alloy has lowest elastic modulus.

The resonance curves SnSb_{13-x}X_x alloys are shown in Figure (4). Calculated internal friction and thermal diffusivity of SnSb_{13-x}X_x alloys are seen in

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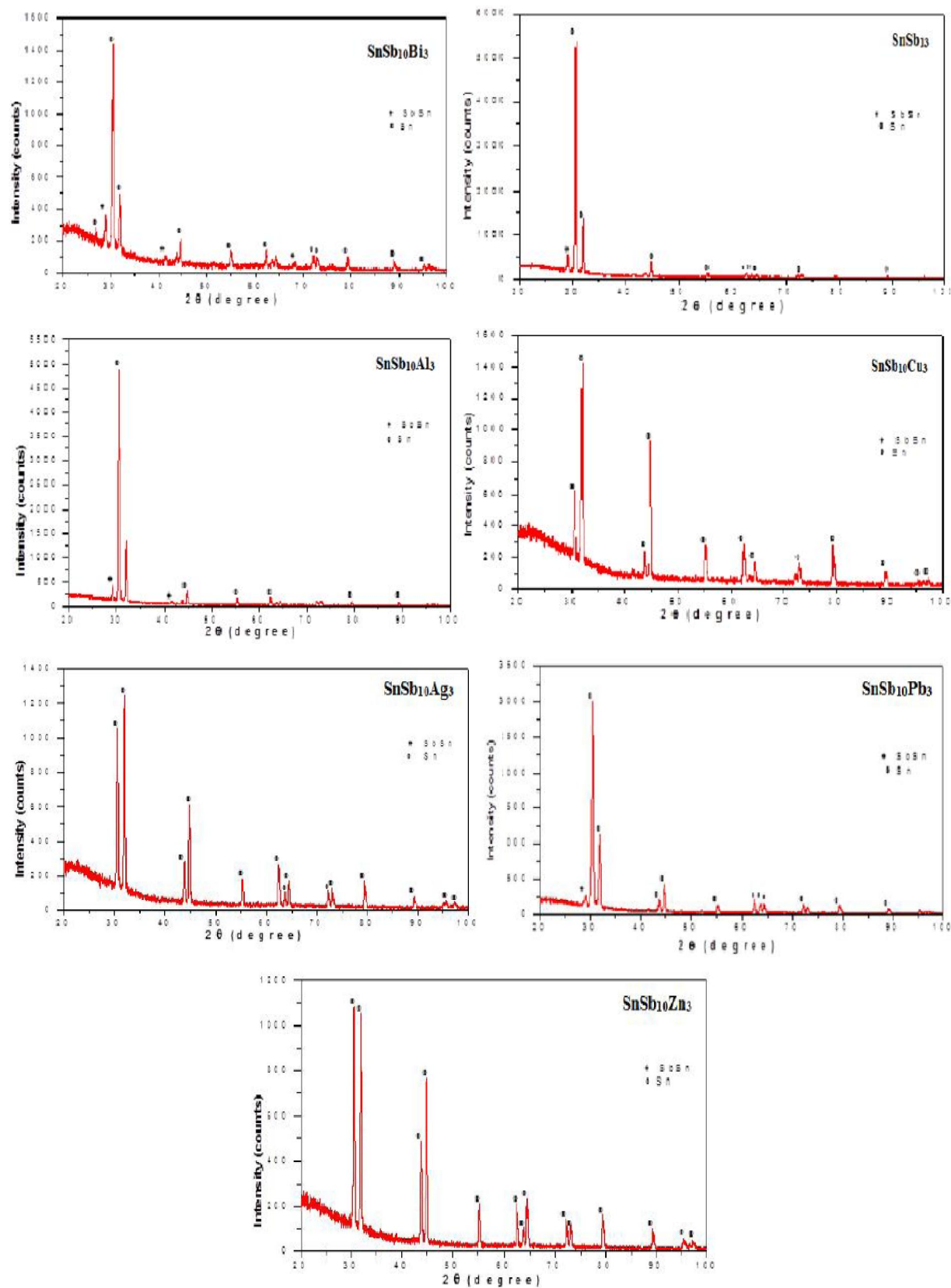
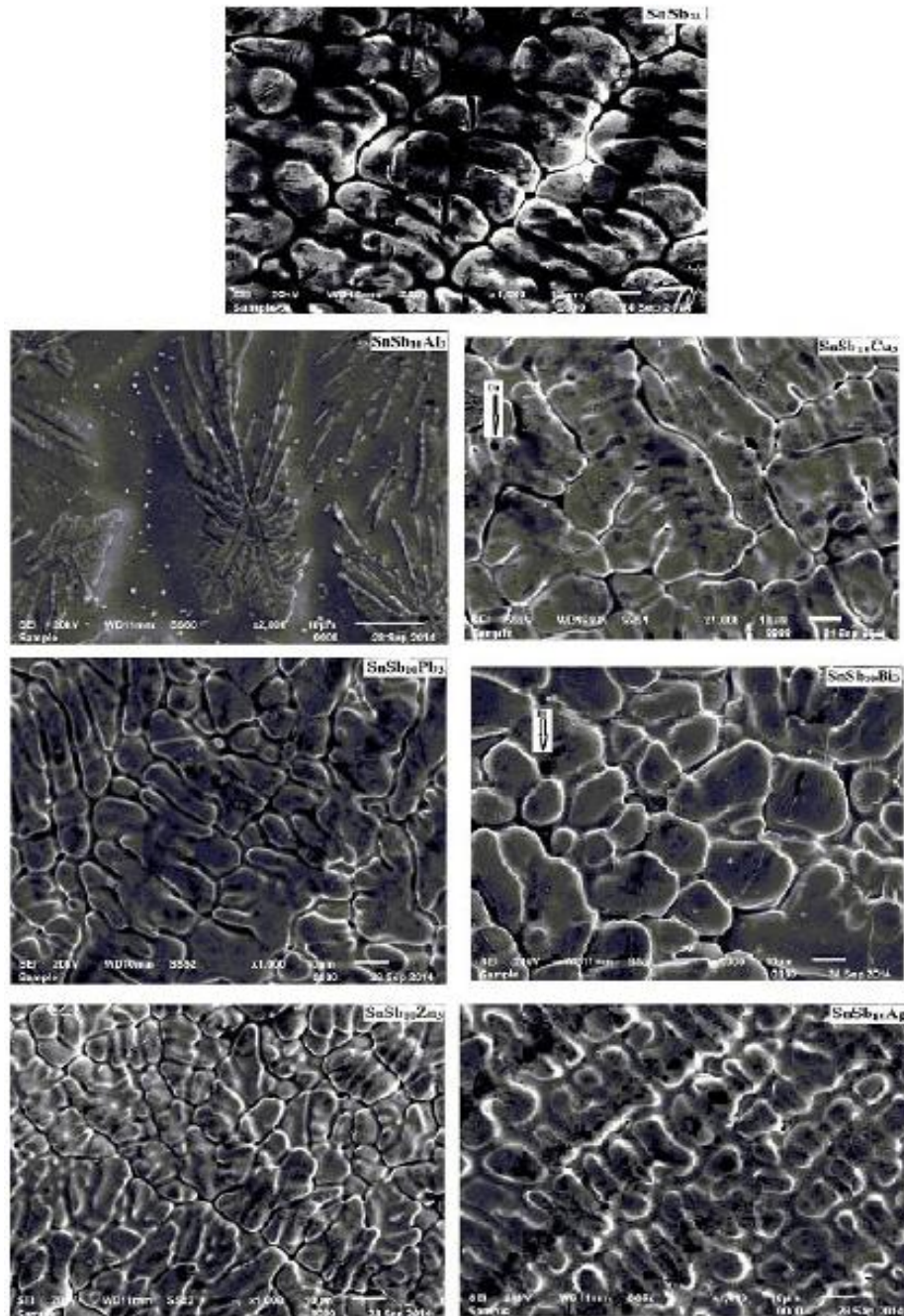
Figure 1 : X-ray diffraction patterns of SnSb_{13-x}X alloys

TABLE 1 : Lattice parameters and crystal size of β -Sn in $\text{SnSb}_{13-x}\text{X}_x$ alloys

Alloys	a Å	c Å	V Å ³	τ Å
$\text{Sn}_8\text{Sb}_{13}$	5.86	3.17	108.735	282.56
$\text{Sn}_{87}\text{Sb}_{10}\text{Cu}_3$	5.85	3.195	109.811	368.89
$\text{Sn}_{87}\text{Sb}_{10}\text{Bi}_3$	5.87	3.176	109.322	329.01
$\text{Sn}_{87}\text{Sb}_{10}\text{Al}_3$	5.86	3.18	109.039	370.45
$\text{Sn}_{87}\text{Sb}_{10}\text{Pb}_3$	5.86	3.174	108.883	355.44
$\text{Sn}_{87}\text{Sb}_{10}\text{Zn}_3$	5.85	3.186	108.898	438.41
$\text{Sn}_{87}\text{Sb}_{10}\text{Ag}_3$	5.85	3.181	109.079	420.09

Figure 2 : SEM of $\text{SnSb}_{13-x}\text{X}_x$ alloys

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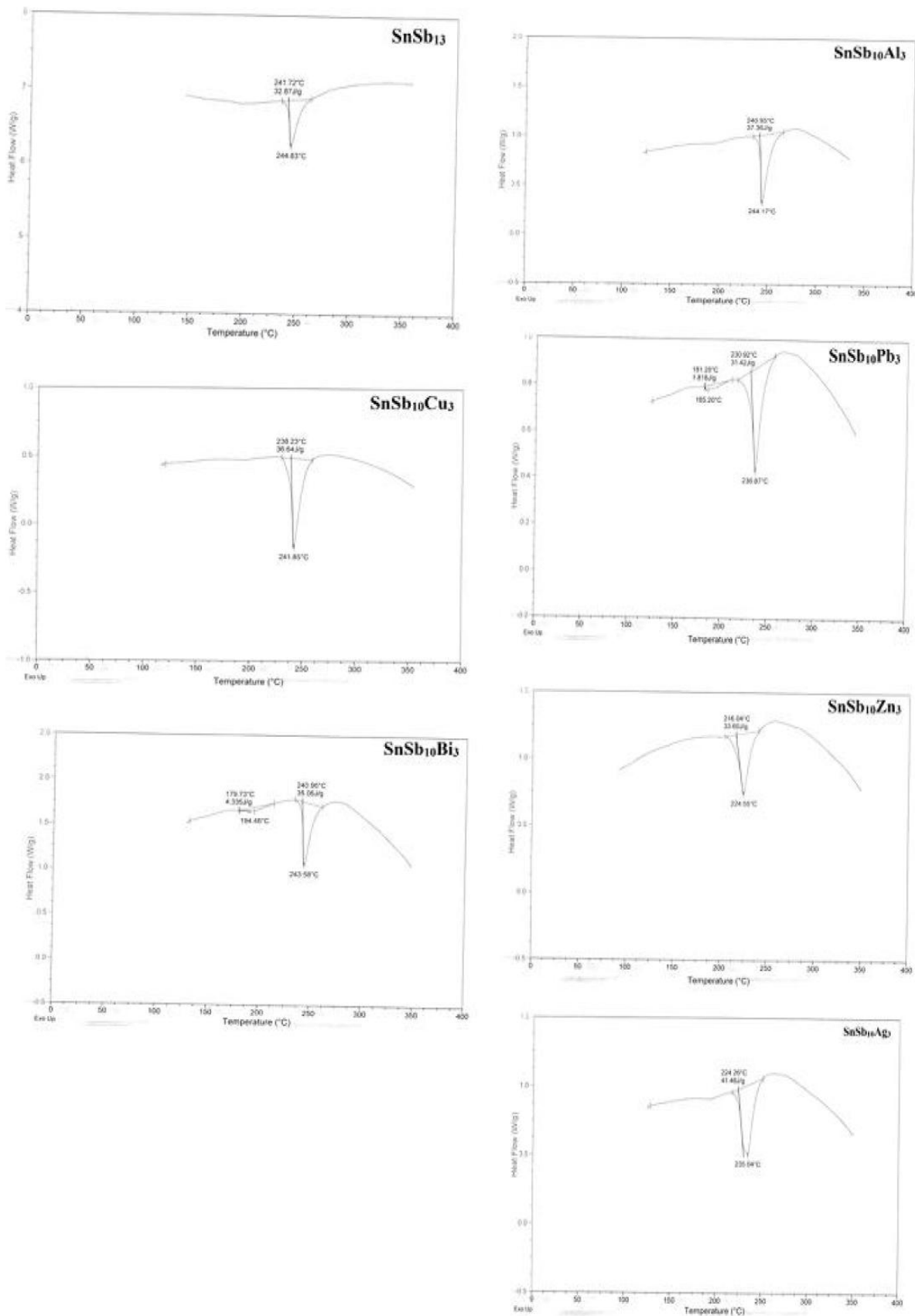


Figure 3 : DSC of SnSb_{13-x}X alloys

TABLE 2 : Melting temperature and other thermal properties of SnSb_{13-x}X_x alloys

Alloys	Melting point °C	ΔS J/g. °C	C _p J/g. °C
Sn ₈₇ Sb ₁₃	244.83	0.132	2.48
Sn ₈₇ Sb ₁₀ Cu ₃	241.85	0.148	1.88
Sn ₈₇ Sb ₁₀ Bi ₃	243.59	0.141	2.45
Sn ₈₇ Sb ₁₀ Al ₃	244.17	0.15	1.12
Sn ₈₇ Sb ₁₀ Pb ₃	236.87	0.131	1.84
Sn ₈₇ Sb ₁₀ Zn ₃	224.55	0.15	1.92
Sn ₈₇ Sb ₁₀ Ag ₃	235.04	0.18	1.65

TABLE 3 : Elastic moduli, internal friction and thermal diffusivity of SnSb_{13-x}X_x alloys

Alloys	E(GPa)	μ(GPa)	G (GPa)	Q ⁻¹	D _{th} x 10 ⁻⁸ m ² /sec
Sn ₈₇ Sb ₁₃	29.77	10.98	34.48	0.068	12.38
Sn ₈₇ Sb ₁₀ Cu ₃	34.92	12.65	48.58	0.062	8.62
Sn ₈₇ Sb ₁₀ Bi ₃	39.07	14.16	53.90	0.095	2.93
Sn ₈₇ Sb ₁₀ Al ₃	24.24	8.78	34.01	0.091	6.07
Sn ₈₇ Sb ₁₀ Pb ₃	33.02	12.15	39.15	0.025	9.43
Sn ₈₇ Sb ₁₀ Zn ₃	42.11	15.36	54.49	0.05	6.12
Sn ₈₇ Sb ₁₀ Ag ₃	28.23	10.21	40.29	0.037	33.94

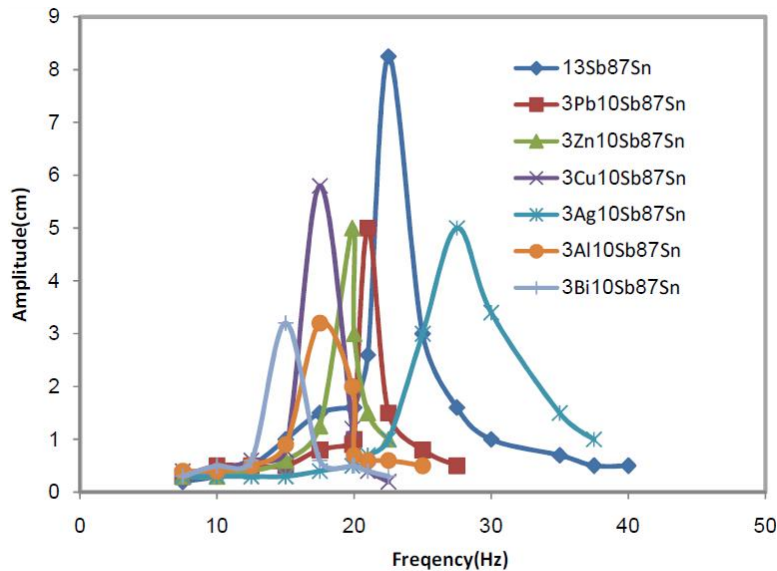
Figure 4 : Resonance curves of SnSb_{13-x}X_x alloys

TABLE 3. Internal friction of SnSb₁₃ alloy varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. The Sn₈₇Sb₁₀Bi₃ alloy has highest internal friction but Sn₈₇Sb₁₀Pb₃ alloy has lowest internal friction.

Vickers microhardness and minimum shear stress

The hardness is the property of material, which gives it the ability to resist being permanently deformed when a load is applied. Vickers hardness of SnSb_{13-x}X_x alloys at 10 gram force and indentation

time 5 sec are shown in TABLE 4. The minimum shear stress (τ_m) value of SnSb_{13-x}X_x alloys was calculated using the equation^[9], where ν is Poisson's ratio of the elements in the alloy and then listed in TABLE 4.

$$\tau_m = \frac{1}{2} H_v \left\{ \frac{1}{2} (1 - 2\nu) + \frac{2}{9} (1 + \nu) [2(1 + \nu)]^{\frac{1}{2}} \right\}$$

Vickers hardness of SnSb₁₃ alloy varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. The Sn₈₇Sb₁₀Cu₃ alloy has lowest hardness but Sn₈₇Sb₁₀Zn₃ alloy has highest hardness.

TABLE 4 : Vickers hardness and minimum shear stress of SnSb_{13-x}X alloys

Alloys	H _v , kg/mm ²	μ _n kg/mm ²
Sn ₈₇ Sb ₁₃	23.033±2.1	7.600
Sn ₈₇ Sb ₁₀ Cu ₃	20.42±4.4	6.73
Sn ₈₇ Sb ₁₀ Bi ₃	24.58±5.6	8.11
Sn ₈₇ Sb ₁₀ Al ₃	26.32±4.7	5.38
Sn ₈₇ Sb ₁₀ Pb ₃	28.52±1.8	9.41
Sn ₈₇ Sb ₁₀ Zn ₃	31.78±0.8	14.37
Sn ₈₇ Sb ₁₀ Ag ₃	26.95±4.1	8.89

TABLE 5 : Electrical and thermal conductivities of SnSb_{13-x}X alloys

Alloys	ρ x 10 ⁻⁸ Ωm	σ x 10 ⁶ Ω ⁻¹ .m ⁻¹	K W.m ⁻¹ K ⁻¹
Sn ₈₇ Sb ₁₃	85.95	1.16	1.81
Sn ₈₇ Sb ₁₀ Cu ₃	73.66	1.35	2.1
Sn ₈₇ Sb ₁₀ Bi ₃	59.32	1.68	2.6
Sn ₈₇ Sb ₁₀ Al ₃	73.66	1.35	2.1
Sn ₈₇ Sb ₁₀ Pb ₃	67.3	1.485	2.3
Sn ₈₇ Sb ₁₀ Zn ₃	97.05	1.03	1.61
Sn ₈₇ Sb ₁₀ Ag ₃	91.56	1.09	1.7

TABLE 6 : Corrosion potential, corrosion current and corrosion rate of SnSb_{13-x}X alloys

Alloys	E _{corr} V	i _{corr} μA cm ⁻²	C.R mpy
Sn ₈₇ Sb ₁₃	-0.519	85.00	38.82
Sn ₈₇ Sb ₁₀ Cu ₃	-0.521	144.0	65.81
Sn ₈₇ Sb ₁₀ Bi ₃	-0.764	78.50	35.85
Sn ₈₇ Sb ₁₀ Al ₃	-0.512	154.0	70.19
Sn ₈₇ Sb ₁₀ Pb ₃	-0.519	148.0	67.49
Sn ₈₇ Sb ₁₀ Zn ₃	-0.521	87.90	40.15
Sn ₈₇ Sb ₁₀ Ag ₃	-0.517	98.40	44.95

Electrical resistivity and thermal conductivity

Plastic deformation raises the electrical resistivity as a result of the increased number of electron scattering centers. Crystalline defects serve as scattering center for conduction electrons in metals, so the increase in their number raises the imperfection. Electrical resistivity and calculated electrical and thermal conductivities of SnSb_{13-x}X alloys are shown in TABLE (5). Electrical resistivity of SnSb₁₃ alloy varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. That is because Bi, Cu, Al, Pb, Zn and Ag atoms dissolved in the alloy matrix playing as scattering center for conduction electrons caused a change in matrix structure of SnSb₁₃ alloy.

Electrochemical corrosion behavior

Figure (5) shows electrochemical polarization curves for SnSb_{13-x}X (X=Bi, Cu, Al, Pb, Zn, Ag and x=3 wt. %) alloys in 0.5 M HCl. From this figure, the corrosion potential of the SnSb_{13-x}X alloys exhibited a negative potential. Also, the cathodic and the anodic polarization curves showed similar corrosion trends. TABLE (6) presents the corrosion potential (E_{Corr}), corrosion current (I_{Corr}), and corrosion rate (Corr_{Rate}) of SnSb_{13-x}X alloys. The results show that, the corrosion rate in 0.5M HCl of SnSb₁₃ alloy varied after adding Bi, Cu, Al, Pb, Zn and Ag contents. The Sn₈₇Sb₁₀Bi₃ alloy has lowest corrosion rate but Sn₈₇Sb₁₀Al₃ alloy has highest corrosion rate. That is because adding Bi, Cu, Al, Pb, Zn and Ag contents caused heterogeneous microstructure with affected on microsegregation and reactiv-

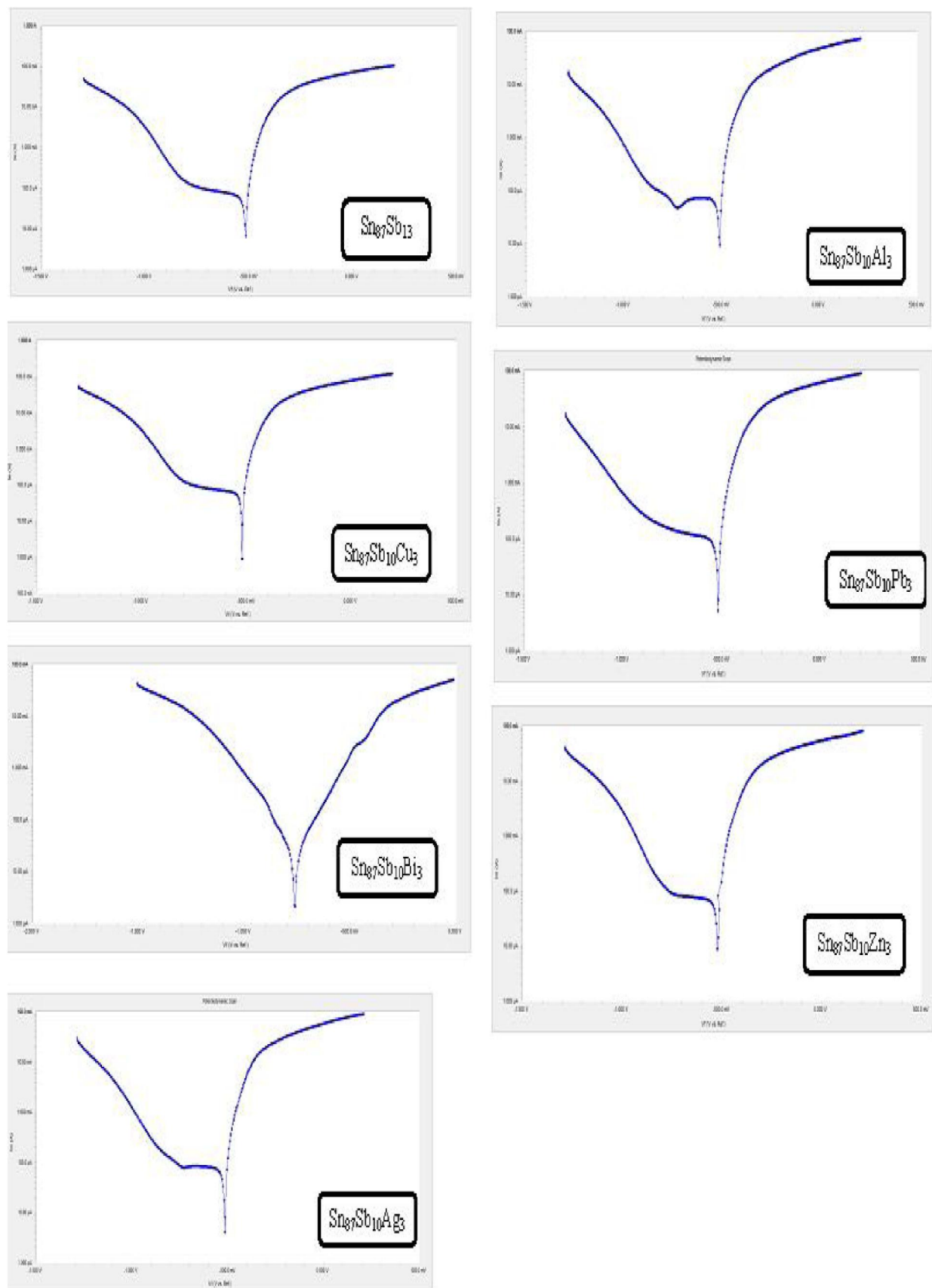


Figure 5 : Electrochemical polarization curves of $\text{SnSb}_{13-x}\text{X}_x$ alloys

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ity of atoms with HCl solution.

CONCLUSIONS

Matrix structure of SnSb₁₃ alloy changed after adding Bi, Cu, Al, Pb, Zn and Ag contents due to dissolved atoms forming solid solution and other accumulated atoms forming traces of phases. The Sn₈₇Sb₁₀Bi₃ alloy has highest internal friction but Sn₈₇Sb₁₀Pb₃ alloy has lowest internal friction. The Sn₈₇Sb₁₀Zn₃ alloy has highest elastic modulus but Sn₈₇Sb₁₀Al₃ alloy has lowest elastic modulus. The Sn₈₇Sb₁₀Cu₃ alloy has lowest hardness but Sn₈₇Sb₁₀AZn₃ alloy has highest hardness. The Sn₈₇Sb₁₀Bi₃ alloy has lowest corrosion rate but Sn₈₇Sb₁₀Al₃ alloy has highest corrosion rate.

REFERENCES

- [1] A.B.El-Bediwi, A.R.Lashin, A.Mossa, M.Kamal; MSAIJ, **6**, 37 (2010).
- [2] M.Kamal, A.El-Bediwi, M.El-Shobaki; Radia.Eff.Def.Sol., **161**, 549 (2006).
- [3] M.O.Bora, O.Coban, T.Sinmazcelik, V.Gunay, M.Zeren, Mater.And Design, **31**, 2707 (2010).
- [4] A.B.El- Bediwi, El Said Gouda, M.Kamal; AMSE, 65, n° 1, Modeling C- (2004).
- [5] M.Kamal, A.Abdel-Salam, J.C.Pieri; J.Mater.Sci., **19**, 3880 (1984).
- [6] A.El-Bediwi, A.Lashin, M.Mossa, M.Kamal; Mater.Sci.Engineering A, **528**, 3568 (2011).
- [7] H.Xiaowu, L.Shuangming, L.Lin, F.Hengzhi; The Chinese Journal of Nonferrous Metals, **14(1)** 93 (2004).
- [8] E.Schreiber, O.L.Anderson, N.Soga; Elastic constant and their measurements, McGraw-Hill, New York, 82 (1973).
- [9] S.Timoshenko, J.N.Goddier; "Theory of elasticity, 2nd Edition", McGraw-Hill, New York, 277 (1951).
- [10] K.Nuttall; J.Inst.Met., **99**, 266 (1971).