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Structure and mechanical properties of modified tin- antimony- lead bearing alloy

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ABSTRACT

Influence of adding alloying elements such as copper, aluminum, bismuth and indium on microstructureand mechanical properties of $Sn_{80}Sb_{15}Pb_5$ alloy have been investigated. All measured properties, such as elastic modulus, internal friction and Vickers hardnessof $Sn_{80}Sb_{15}Pb_5$alloy varied after adding these alloying elements due to a change in its matrix structure. Matrix microstructure, (such as formed phases, lattice parameters and crystal size), of $Sn_{80}Sb_{15}Pb_5$ alloy varied after adding Cu, Al, Bi and In contents as shown in x-ray diffraction analysis and scanning electron micrographs. The $Sn_{78}Sb_{15}Pb_5Cu_2$alloy has best bearing properties, lower internal friction, higher hardness, self-lubricate and adequate coast for automotive applications.

KEYWORDS

Bearing alloy;
Microstructure;
Hardness;
Internal friction;
Elastic modulus.

INTRODUCTION

The development of new advanced material is an important activity for continues progress in science and technology. 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. Considerable research and development efforts are underway towards the development of tin-based bearing alloys. Tensile properties of Sn 5%Sb, Sn 5%Sb 1.5%Bi and Sn 5%Sb 1.55%Cu alloys have been investigated at various strain rates ranging from 5×10^{-4} to 1×10^{-2} s^{-1} over the wide temperature range of 298-400 K[1]. Adding 1.5% Bi and 1.5% Cu to the Sn 5%Sb alloy improved both strength and ductility of the base alloy. Creep behavior, 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[2]. Elastic modulus and internal friction values of Sn 10%Sb 2%Cu 2%X (X = Pb, Ag, Se, Cd and Zn) alloysare affected by changing Sn matrix microstructure. The structure, electrical resistivity and elastic modulus of Sn 7%Sb and Sn 7%Sb X (X = Cu, Ag, or Cu and Ag) and (63-x)Pb30%Sn7%Sbx%Cu [x=0 or x≤2.5] rapidly solidified alloys have been investigated[3, 4]. Sn 7%Sb 2%Ag2%Cu has the best properties as bearing alloy. Also adding Cu to Pb30%Sn7%Sb decreases its electrical resistivity, elastic modulus and internal friction. The elastic modulus, internal friction and stiffness values of quenched Sn-Sb bearing alloy have been evaluated[5]. Adding small amounts (1 wt. %) of Cu or Ag improved the mechanical properties of Sn-Sb bearing alloys. Also isothermal annealing for 2 and 4 h at 120, 140 and 160 °C caused variations in the elastic modulus, internal friction and stiffness values of Sn-Sb based bearing alloys. Creep behavior of Sn-5%Sb alloy was studied by long time Vickers indentation testing at room temperature[6, 7]. The indentation creep tests performed at room temperature on cast and wrought Sn-5%Sb alloys occurs in these alloys and capable of evaluating creep behavior of materials using small specimens. Creep behavior of Sn–40% Pb–2.5% Sb peritectic alloy having different grain sizes was studied by long time Vickers indentation testing at room temperature[8]. The tribological properties of tin-based bearing alloys with different compositions, (low Sb content (7%) and the other with high Sb content (20%)), have been investigated[9]. The results showed that, increasing Sb content from 7.5% to 20% provided an increase in hardness. The effect of solidification rate, heating and micro additions on microstructure and hardness of tin-based white metals have been investigated[10, 11]. The results showed that, rapid cooling suppresses formation and growth of SbSn cuboids and increases hardness. Structure, hardness, mechanical and electrical transport properties of $Sn_{90-x}Sb_{10}Bi_x$ (x = 0, or x ≥1) alloys have been investigated[12]. The electrical resistivity and hardness values of Sn10%Sbincreased but internal friction, elastic modulus and thermal diffusivity values decreased by adding bismuth content. The effects of minor additives of Ag and Cu on the as-cast microstructure and creep properties of the Sn 5%Sb alloy have been investigated[13]. Small additions of Ag and Cu elements could effectively change the creep behavior of the Sn 5%Sb alloy. 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[14]. Also scratch hardness values of the WM5 materials are higher than WM2 generally. The directionally solidified microstructure of Sn-16%Sb hyperperitectic alloy has been investigated at various solidification rates using a high-thermal gradient directional solidification apparatus[15]. The results show, volume fraction of the SnSb phase firstly decreased and then increased when the solidification rate increased. The aim of this research was to improve mechanical properties of $Sn_{80}Sb_{15}Pb_5$ bearing alloy by adding different alloying elements.

EXPERIMENTAL WORK

In this work $Sn_{80-x}Sb_{15}Pb_5X_x$(X= Cu, Al, Bi and In) alloys were molten in the muffle furnace using high purity, more than 99.95%, tin, antimony, bismuth, lead, copper, aluminum and indium. The resulting ingots were turned and re-melted 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 cuter. Structure of used alloys was performed using an Shimadzu X–ray Diffractometer (Dx–30, Japan)of Cu–Kα radiation with λ=1.54056 Å 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. AlsoScanning electron microscope JEOL JSM-6510LV, Japan was used to study structure. 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[16-18].

RESULTS AND DISCUSSIONS

Structure

X-ray diffraction patternsof $Sn_{80}Sb_{15}Pb_5$ and $Sn_{78}Sb_{15}Pb_5Cu_2$rapidly solidified alloys have lines corresponding to β- Sn,Pb and SbSn intermetallic phases as shown in Figure 1. But x-ray diffraction patternsof $Sn_{78}Sb_{15}Pb_5Al_2$ and $Sn_{75}Sb_{15}Pb_5In_5$ alloys have lines corresponding to β- Sn and SbSn intermetallic phases. Also $Sn_{75}Sb_{15}Pb_5In_5$ alloyhave lines corresponding to β- Sn, Pb, SbSn and Pb_7Bi_3 intermetallic phases. X-ray analysis details, (formed

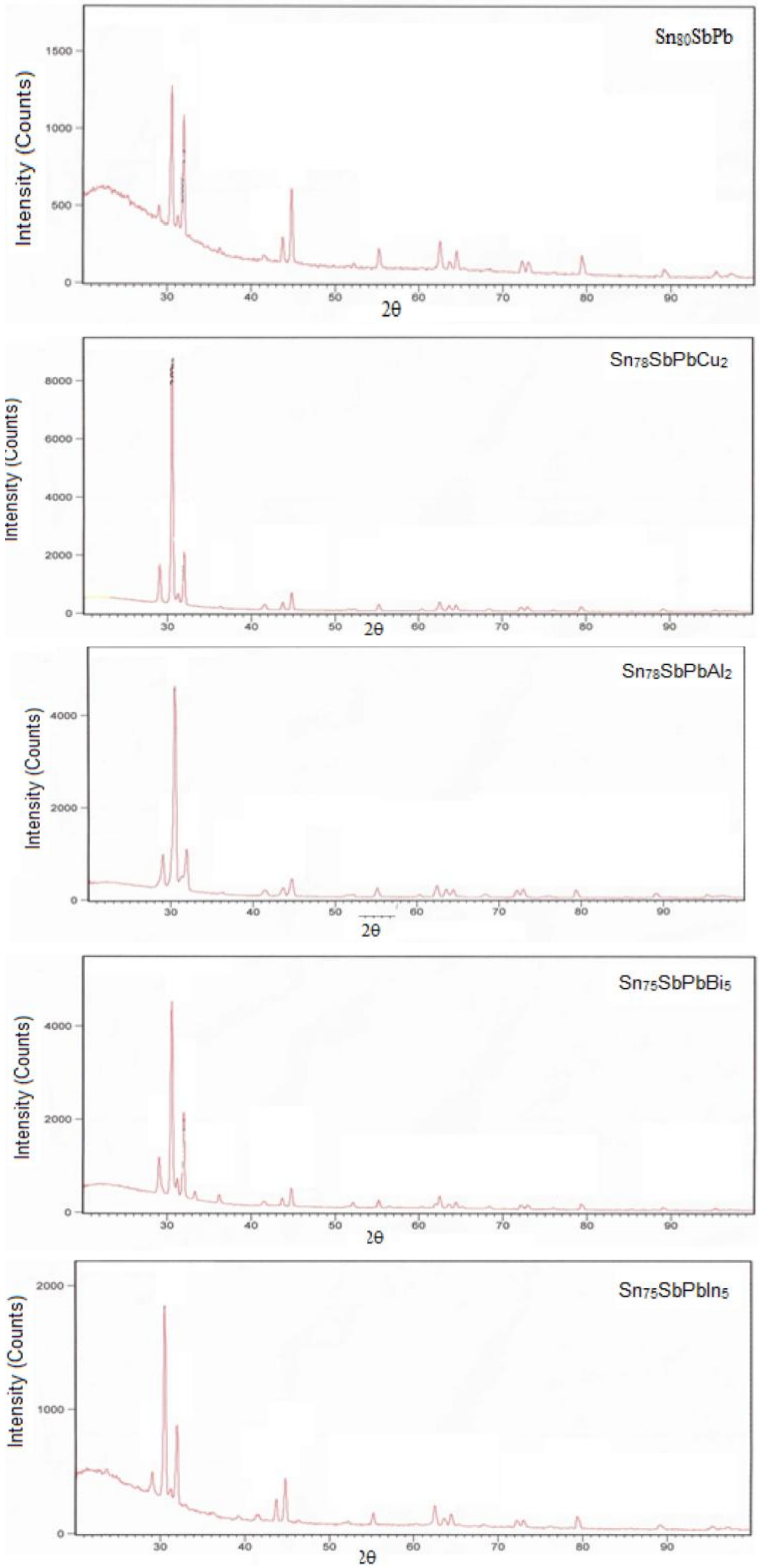

Figure 1 : X-ray diffraction patterns of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

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TABLE 1 : X-ray diffraction analysis of $Sn_{80-x}Sb_{15}Pb_{5}X_{x}$ alloys

$Sn_{80}Sb_{15}Pb_{5}$					
2θ	d Å	Int. %	FWHM	Phase	hkl
29.0519	3.07368	9.56	0.3149	SbSn	101
30.5386	2.92735	100	0.2362	Sn	200
31.2790	2.85974	10.36	0.3262	Pb	111
31.9673	2.79971	83.88	0.2558	Sn	101
41.5973	2.17113	2.96	0.9446	SbSn	012
43.7916	2.06730	17.91	0.2755	Sn	220
44.8534	2.02080	52.36	0.2755	Sn	211
55.2148	1.66362	13.53	0.2755	Sn	301
62.5048	1.48597	19.89	0.2362	Sn	112
63.6419	1.46214	5.40	0.3149	Sn	400
64.4563	1.44562	13.50	0.2362	Sn	400
72.2830	1.30716	7.90	0.3936	Sn	420
73.0363	1.29552	7.19	0.3936	Sn	411
79.3677	1.20732	12.74	0.1968	Sn	312
89.1460	1.09849	5.13	0.3149	Sn	431
95.4464	1.04194	3.94	0.4728	Sn	332
97.2603	1.02644	2.26	1.1520	Sn	521
$Sn_{78}Sb_{15}Pb_{5}Cu_{2}$					
2θ	d Å	Int. %	FWHM	Phase	hkl
29.0849	3.07027	15.73	0.2165	SbSn	101
30.5461	2.92665	100	0.2755	Sn	200
31.3013	2.85774	4.41	0.2362	Pb	111
31.9932	2.79751	21.51	0.2558	Sn	101
41.4549	2.17826	1.80	0.4723	SbSn	012
43.7572	2.06885	3.25	0.2755	Sn	220
44.8526	2.02083	6.90	0.2952	Sn	211
55.1786	1.66462	2.43	0.2362	Sn	301
62.4977	1.48613	3.78	0.3149	Sn	112
63.6422	1.46213	2.23	0.3149	Sn	400
64.4160	1.44643	2.32	0.2558	Sn	321
72.1333	1.30950	1.64	0.1968	Sn	420
72.9656	1.29661	1.78	0.2362	Sn	411
79.3595	1.20743	1.98	0.1968	Sn	321
98.1059	1.09888	1.03	0.3149	Sn	431
$Sn_{75}Sb_{15}Pb_{5}Al_{2}$					
2θ	d Å	Int. %	FWHM	Phase	hkl
29.0342	3.07552	16.89	0.2165	SbSn	101
30.5460	2.92666	100	0.2952	Sn	200
32.0205	2.79518	18.11	0.2362	Sn	101
41.3977	2.18114	2.71	0.5510	SbSn	012
43.7834	2.06767	3.68	0.2558	Sn	220
44.8225	2.02214	7.83	0.4330	Sn	211
52.1779	1.75306	1.12	0.3936	SbSn	021
55.2743	1.66197	3.57	0.3346	Sn	301
60.2810	1.53536	1.23	0.3936	SbSn	202
62.4535	1.48707	5.88	0.2558	Sn	112
63.6481	1.46201	3.60	0.3542	Sn	400
64.3904	1.44694	3.83	0.2362	Sn	321

$Sn_{75}Sb_{15}Pb_5Al_2$					
2θ	**d Å**	**Int. %**	**FWHM**	**Phase**	**hkl**
68.4200	1.37122	1.45	0.3936	SbSn	113
72.1870	1.30866	3.70	0.2558	Sn	420
72.9460	1.29691	4.05	0.3149	Sn	411
79.2768	1.20848	3.44	0.1968	Sn	312
88.9557	1.10034	1.68	0.4723	Sn	431
95.2871	1.04326	1.45	0.4330	Sn	332
97.1764	1.02710	1.05	0.5760	Sn	521

$Sn_{75}Sb_{15}Pb_5Bi_5$					
2θ	**d Å**	**Int. %**	**FWHM**	**Phase**	**hkl**
29.0444	3.07446	18.60	0.2362	SbSn	101
30.5190	2.92919	100	0.2755	Sn	200
31.2507	2.86226	8.72	0.1968	Pb	111
31.9549	2.80077	43.73	0.2558	Sn	101
33.3137	2.68985	4.28	0.1968	Pb_7Bi_3	012
36.1408	2.48541	4.24	0.2165	Pb	220
41.5735	2.17232	2.46	0.3149	SbSn	012
43.6997	2.07144	4.16	0.2755	Sn	220
44.7317	2.02601	9.14	0.2952	Sn	211
52.1027	1.75542	2.74	0.2165	SbSn	021
55.1453	1.66555	3.96	0.2165	Sn	301
61.9152	1.49870	2.40	0.2362	Sn	112
62.4148	1.48790	6.31	0.1968	Sn	112
63.5493	1.46405	2.17	0.3149	Sn	400
64.3125	1.44850	3.10	0.2362	Sn	321
68.2817	1.37366	1.18	0.4723	SbSn	113
72.1098	1.30987	2.11	0.3936	Sn	420
72.9200	1.29730	2.17	0.3149	Sn	411
79.2590	1.20870	2.93	0.1771	Sn	312
89.0033	1.09988	1.31	0.3936	Sn	431
95.2270	1.04290	1.14	0.3840	Sn	332

$Sn_{75}Sb_{15}Pb_5In_5$					
2θ	**d Å**	**Int. %**	**FWHM**	**Phase**	**hkl**
29.0496	3.07392	11.33	0.1574	SbSn	101
30.5211	2.92900	100.00	0.2558	Sn	200
31.9496	2.80122	40.66	0.2362	Sn	101
41.3939	2.18133	2.85	0.4723	SbSn	012
43.7470	2.06930	11.49	0.2558	Sn	220
44.8054	2.02285	22.67	0.2952	Sn	211
52.0285	1.75774	1.04	0.9446	SbSn	021
55.2093	1.66377	6.15	0.3149	Sn	301
62.4556	1.48703	10.42	0.1968	Sn	112
63.4658	1.46577	3.31	0.3542	Sn	400
64.4241	1.44626	6.18	0.2755	Sn	321
72.1804	1.30876	3.65	0.3936	Sn	411
72.9904	1.29622	3.68	0.3149	Sn	112
79.3186	1.20795	6.03	0.1968	Sn	400
89.2018	1.09794	2.32	0.4723	Sn	431
95.3809	1.4162	1.90	0.6720	Sn	332

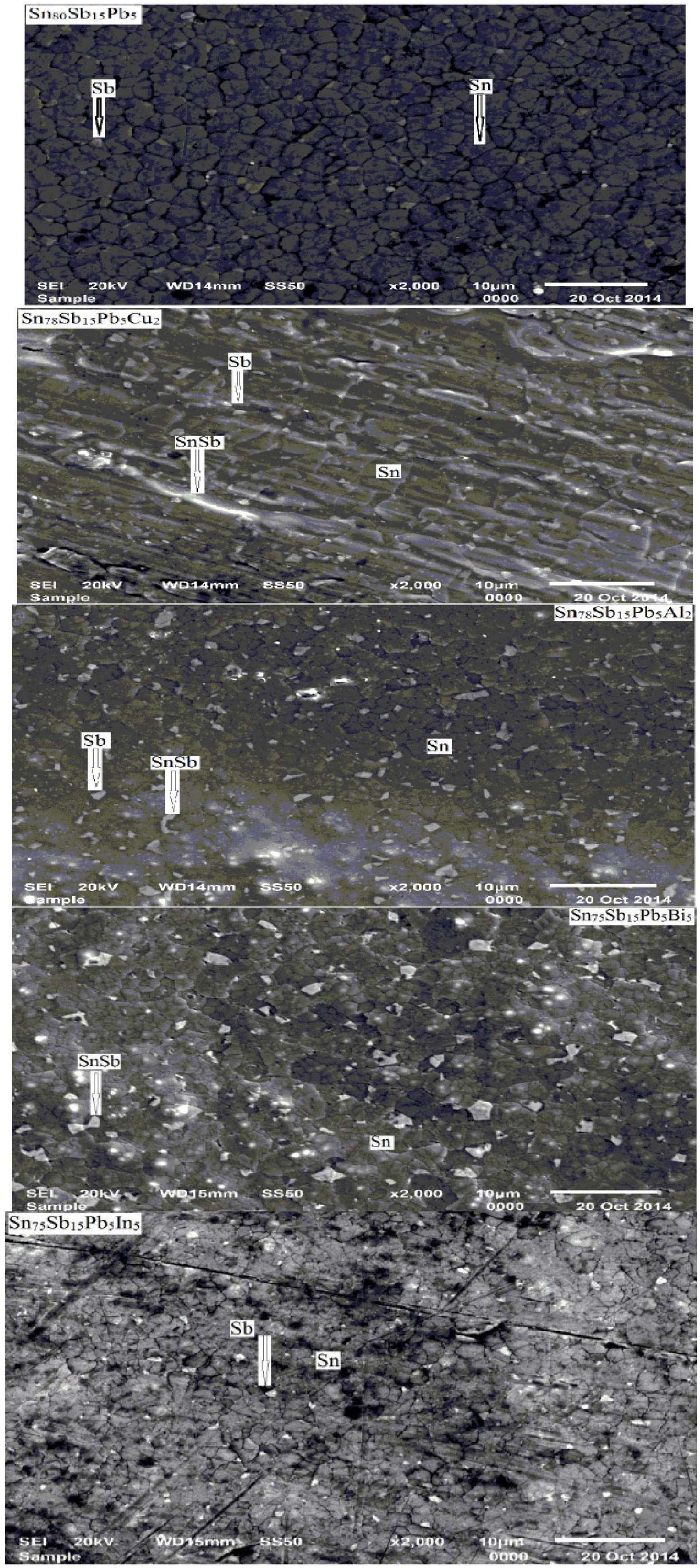

Figure 2 : SEM of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

TABLE 2 : Lattice parameters, (a and c), unit volume cell and crystal size of β- Sn phase in $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

Alloys	a Å	c Å	V Å^3	τ Å
$Sn_{80}Sb_{15}Pb_5$	5.855	3.184	109.144	317.252
$Sn_{78}Sb_{15}Pb_5Cu_2$	5.853	3.185	109.109	365.787
$Sn_{78}Sb_{15}Pb_5Al_2$	5.853	3.187	109.189	315.463
$Sn_{75}Sb_{15}Pb_5Bi_5$	5.8584	3.215	110.347	352.236
$Sn_{75}Sb_{15}Pb_5In_5$	5.858	3.186	109.347	319.883

TABLE 3 : Elastic modulus, internal friction and thermal diffusivity of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

Alloys	E GPa	μ GPa	B GPa	Q^{-1} x10^{-3}	D_{th} x10^{-4} cm^2/s
$Sn_{80}Sb_{15}Pb_5$	24.28±2.4	8.929	28.80	34.3	21.12
$Sn_{78}Sb_{15}Pb_5Cu_2$	17.33±1.3	5.641	18.14	30.0	18.41
$Sn_{78}Sb_{15}Pb_5Al_2$	19.83±1.4	7.322	22.61	38.6	22.05
$Sn_{75}Sb_{15}Pb_5Bi_5$	24.2±2	8.939	28.50	40.5	13.12
$Sn_{75}Sb_{15}Pb_5In_5$	14.53±1.6	5.344	17.20	28.9	25.97

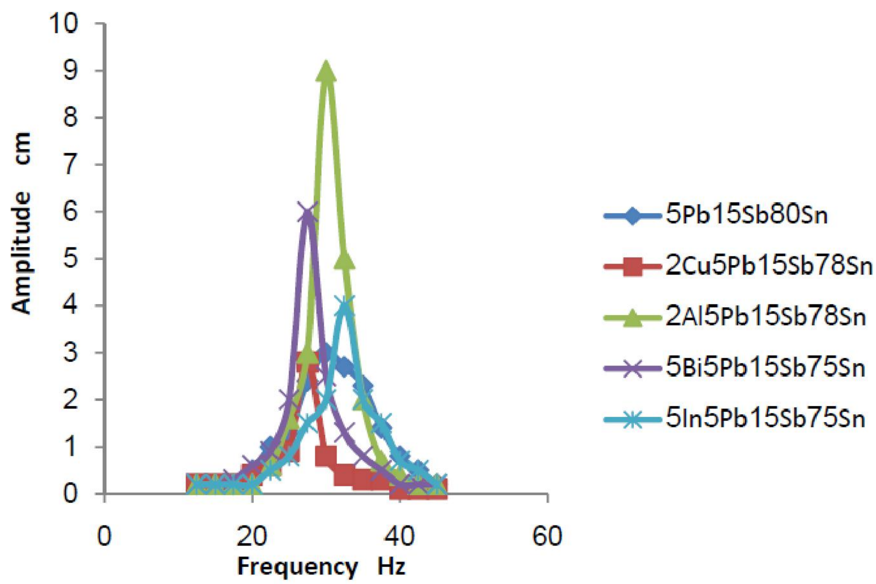

Figure 3 : Resonance curves of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

phases, intensity, broadness, position (2θ) and area under peaks, miller indices), of $Sn_{80-x}Sb_{15}Pb_5X_x$ (X= Cu, Al, Bi and In) alloys are listed in TABLE 1. From these analysis, it's obvious that Cu, In, Bi and Al atoms dissolved in Sn matrix formed a solid solution and some Bi atoms react with Pb formed Pb_7Bi_3 intermetallic phase.

Lattice parameters, (a and c), and unit volume cell of β- Sn phase in $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys were determined and then listed in TABLE (2). Lattice parameters, a and c, unit cell volume and crystal size of β- Snin $Sn_{80}Sb_{15}Pb_5$ varied after adding Bi, Cu, Al and In contents. That is because Bi, Cu, Al and In atoms dissolved in Sn matrix alloy forming a solid solution and other accumulated atoms forming traces of phases.

Scanning electron micrographs, SEM, of $Sn_{80-x}Sb_{15}Pb_5X_x$ (X= Cu, Al, Bi and In) alloys show heterogeneity structure as shown in Figure 2. Microstructure of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys show β- Sn matrix, SbSnphase and other accumulated atoms forming traces of atoms and that is agreed with x-ray results.

Elastic modulus and internal friction

The elastic constants are directly related to atomic bonding and structure. Elastic modulusvalues

TABLE 4 : Vickers microhardness and minimum shear stress of $Sn_{80-x}Sb_{15}Pb_5X_x$ alloys

Alloys	H_v kg/mm^2	τ_m kg/mm^2
$Sn_{80}Sb_{15}Pb_5$	24.61 ±4.26	8.12
$Sn_{78}Sb_{15}Pb_5Cu_2$	31.3±2.22	10.33
$Sn_{78}Sb_{15}Pb_5Al_2$	23.97±1.92	7.91
$Sn_{75}Sb_{15}Pb_5Bi_5$	21.53±1.2	7.1
$Sn_{75}Sb_{15}Pb_5In_5$	27.3±4	9.01

of $Sn_{80-x}Sb_{15}Pb_5X_x$alloys are listed in TABLE (3). Elastic modulus of $Sn_{80}Sb_{15}Pb_5$alloydecreased after adding Bi, Cu, Al and In contents. The $Sn_{75}Sb_{15}Pb_5In_5$alloy has lowest elastic modulus. The resonance curves of $Sn_{80-x}Sb_{15}Pb_5X_x$alloys are shown in Figure (3). Calculated internal friction and thermal diffusivity of $Sn_{80-x}Sb_{15}Pb_5X_x$alloys are shown in TABLE (3). Internal friction of $Sn_{80}Sb_{15}Pb_5$alloyvariedafter adding Bi, Cu, Al and In contents. The $Sn_{75}Sb_{15}Pb_5Bi_5$alloy has highest internal friction but $Sn_{75}Sb_{15}Pb_5In_5$ 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 $Sn_{80-x}Sb_{15}Pb_5X_x$alloys at 10 gram force and indentation time 5 sec are shown in TABLE (4). The minimum shear stress (τ_m) of $Sn_{80-x}Sb_{15}Pb_5X_x$alloys was calculated and then listed in TABLE (4). Vickers hardness of $Sn_{80}Sb_{15}Pb_5$ alloyincreased after adding Cu and In but it decreased after adding Bi and Al contents. The $Sn_{78}Sb_{15}Pb_5Cu_2$alloy has highest hardness but $Sn_{75}Sb_{15}Pb_5Bi_5$ alloy has lowest hardness.

CONCLUSIONS

Matrix microstructure, (formed phases, lattice parameters and crystal size), of $Sn_{80}Sb_{15}Pb_5$ alloy varied after adding Cu, Al, Bi and In contents. Elastic modulus of $Sn_{80}Sb_{15}Pb_5$alloydecreased after adding Bi, Cu, Al and In contents. Internal friction of $Sn_{80}Sb_{15}Pb_5$alloyvariedafter adding Bi, Cu, Al and In contents. Vickers hardness of $Sn_{80}Sb_{15}Pb_5$ alloyincreased after adding Cu and In but it decreased after adding Bi and Al contents.

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