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Microstructural evolution and physical properties of lead-tin alloys synthesized by melt-spinning technique

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ABSTRACT

Lead-tin alloy is frequently used to joint electronic components in electronic packaging and it is a based white metal which has excellent properties for the majority of internal combustion engines, such as crankshaft bearing linings in slow-speed marine diesel engines. By using X-ray diffraction (XRD), transmission electron microscopy (TEM), double bridge method and dynamic resonance technique, microstructure, electrical resistivity, temperature coefficient of resistivity (T.C.R), lattice parameter, crystal size and elastic modulus of Pb-Sn rapidly solidified alloys were investigated. Electrical resistivity, T.C.R, lattice parameter and crystal size of lead- tin alloy is decreased by increasing tin amounts in it but elastic modulus is increased. Tin-3% lead rapidly solidified alloy have better electrical and mechanical properties with adequate melting point as solder alloy for electronic industrial applications. But lead- 5% tin is the better based alloy for bearing applications.

KEYWORDS

Tin-lead alloy-electrical;
Thermal;
Mechanical properties.

INTRODUCTION

Tin-lead solders have been widely used as low temperature joining alloys for quite a time because of their good properties and low cost. The low melting range of tin- lead solders makes them ideal for joining most metals by convenient heating methods with little or no damage to heat sensitive parts. Tin- lead solder alloys can be obtained with melting temperatures as low as 183°C and as high as 315°C. Except for the pure metals and the eutectic solder 63% Sn and 37% Pb, all tin-lead solder alloys melt within a temperature range that varies according to the alloy composition. The creep behavior of eutectic tin- lead solder alloy was investigated using stress relaxation techniques[1] and the young's modulus of Sn-Pb binary alloys was measured with the piezoelectric composite- bar method in the temperature range from room temperature to near the melting point[2]. Using differential scanning calorimetry, the melting temperature of various ratios of lead- tin can be measured and apportion of the phase diagram can be established between the solid and liquid states[3]. Effects of alloying elements on structure, mechanical and electrical properties of Sn-Pb rapidly solidified alloys had bean investigated[4-8]. However, concerns about lead toxicity have resulted in banning of lead- containing solders, the aim of the present study was to eliminate the lead amounts and produce a best Sn-Pb solder alloy by investigate its microstructure and physical properties.

EXPERIMENTAL

Tin- lead alloys were made from high purity tin (99.99%) and lead (99.95%) by conventional melting techniques. 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 ~70μm 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 ~3.7×10^5 K/s. The samples then cut into convenient shape for the measurements using double knife cuter. X-ray diffraction analysis was performed on the flat surface of all samples using an X-ray Diffracto-meter (Dx-30, Shimadzu, Japan) of Cu–K_λ radiation and Ni-filter in the range from 10 to 90 of 2θ value (λ = 0.154056nm, V = 4.5kV, and I = 35mA. Phase identification was carried out by matching each characteristic peak with the Data Cards. The Double–Bridge method was used to measure the electrical resistivity (ρ, Ωm) for the Sn-Pb alloys, which has been shown to be sensitive in the range 10^{-6} to 1.0 Ω. The melting endotherms were obtained using a Shimadzo thermal analyzer. The internal friction Q^{-1}, the thermal diffusivity D_{th}, and the elastic constants were determined using the dynamic resonance method. The value of the dynamic Young modulus E is determined by the following relationship[9-11]:

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

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. From the resonance frequency f_0 at which the peak damping occurs, the thermal diffusivity, D_{th}, can be obtained directly from the following equation:

$$D_{th} = \frac{2d^2 f_0}{\pi}$$

Where d is the thickness of the sample.

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.

RESULTS AND DISCUSSIONS

X-ray diffraction patterns of Sn-Pb rapidly solidified alloys showed the presence of body centered tetragonal tin phase and face centered cubic lead phase as shown in figures 1. The solubility of tin in lead is increased (5% Sn, the Sn phase is disappeared) by using rapid solidification technique. Also figure 2 shows that, the lattice parameters and crystal size of lead are decreased by adding more amount of tin to it.

Figures 3 show the scanning electron micrographs of Sn-Pb rapidly solidified alloys. Pictures show the structure of Sn phase, Pb phase and the mixture of two phases.

Adding more amount of Sn to Pb-Sn alloy decreased its electrical resistivity and increased its elastic modulus as shown in figure 4. That is because adding more Sn content due change in Pb- Sn matrix structural, such as decreased lattice parameters and crystal size with formed more Sn phase which has a lowest electrical resistivity and higher elastic modulus compared

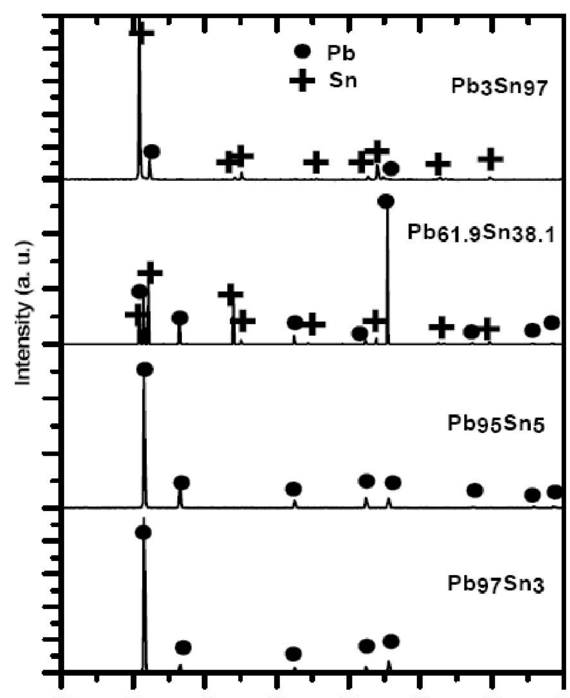


Figure 1 : X-ray diffraction patterns and its analysis of Pb-Sn alloys

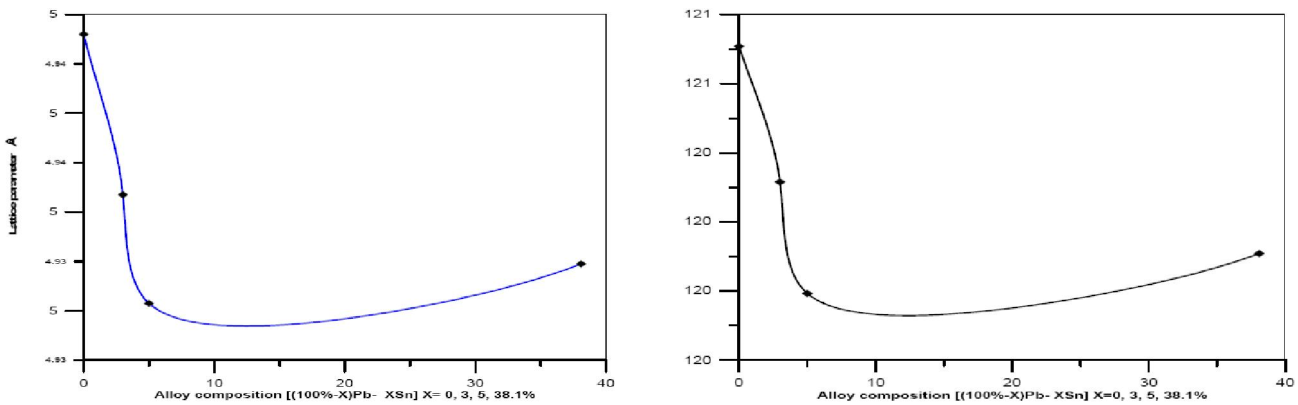


Figure 2 : Lattice parameter and crystal size of lead in Pb-Sn alloys

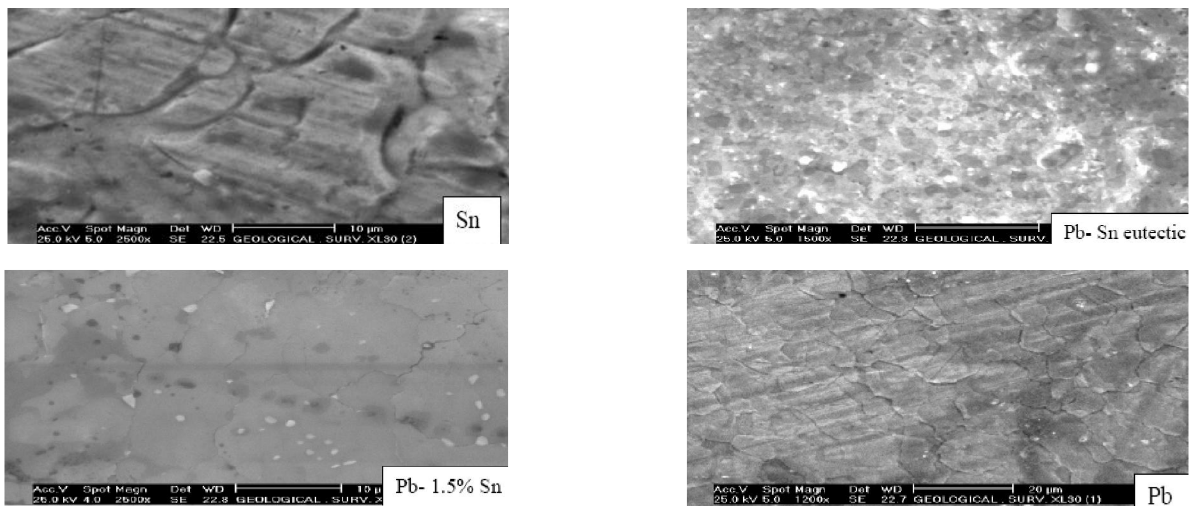


Figure 3 : Scanning electron micrographs of Pb-Sn alloys

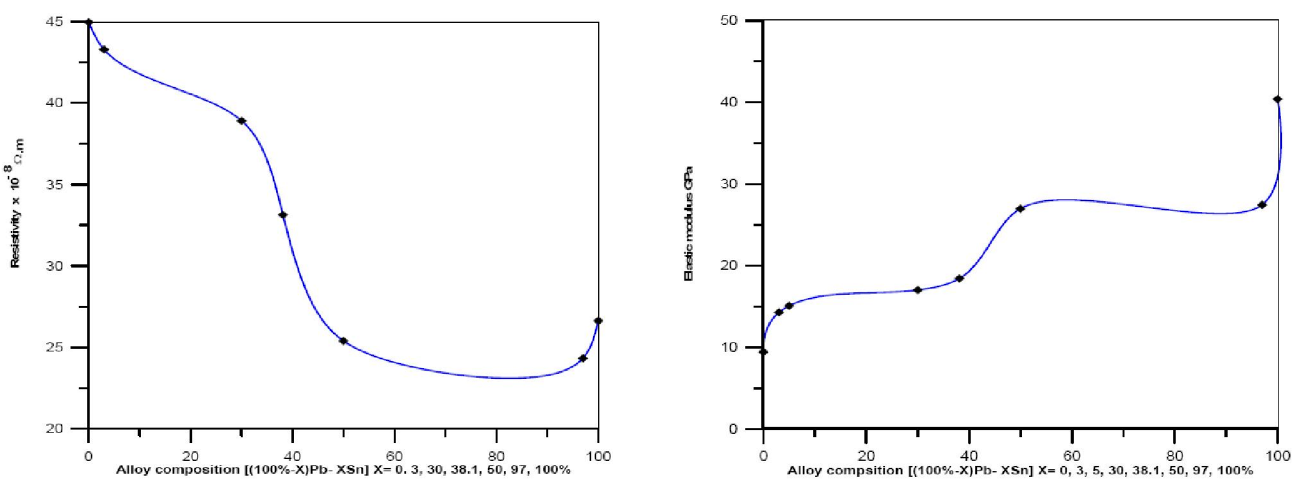
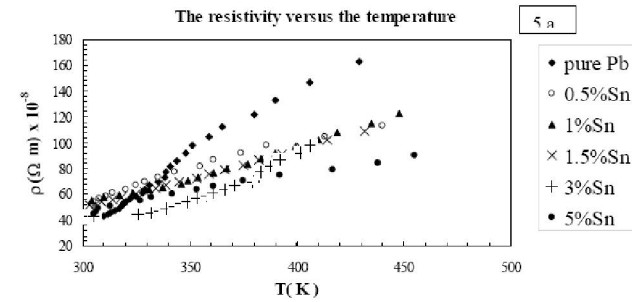


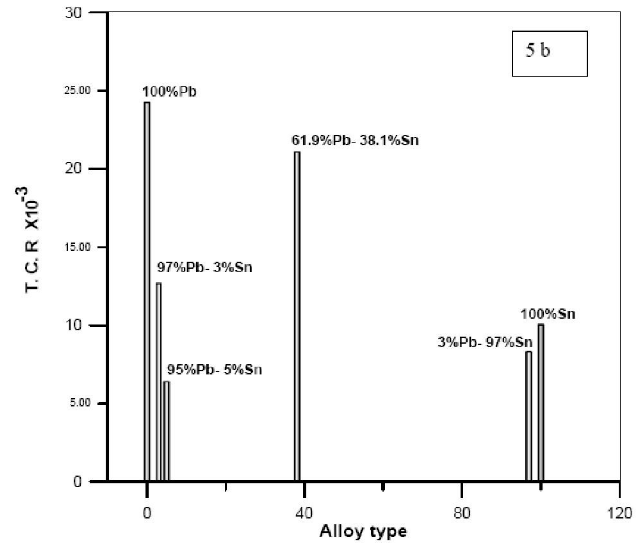
Figure 4 : Electrical resistivity and elastic modulus of Pb-Sn alloys

to Pb phase.

The temperature coefficient of electrical resistance **(α_ρ)** (for a given temperature change) is a structure-sensitive property varying depending on composition by the same law as electrical conductivity, i.e. proportional to ($1/\rho$). It is then essential that the temperature coefficient (α_ρ) can be determined without measuring the linear dimensions of a specimen and therefore, no addition error will be introduced. Figure 5(a) shows the resistivity of Pb-Sn alloys versus temperature. The resistivity is increased with increasing temperature. The temperature coefficient of electrical resistance (α_ρ) can



5(a)



5(b)

Figure 5 : (a) Electrical resistivity versus temperature of Pb-Sn alloys and (b) Temperature coefficient of resistivity of Pb-Sn alloys

be determined from equation:-

$$\alpha_\rho = \frac{d\rho}{dT}\frac{1}{\rho_0}$$

The temperature coefficient of electrical resistance (α_ρ) is decreased by adding more amounts of Sn to Pb- Sn alloy as shown in figure 5(b).

The thermographs, figure 6, show that the melting point of Pb- Sn alloy is decreased by adding more amounts of Sn to it.

CONCLUSIONS

Tin-lead solders are the most widely used of all joining materials. The present study try to produce Pb-Sn solder alloy with eliminate the amounts of lead by adding more amounts of tin to it. Increasing Sn content in Pb-Sn alloy decreased its electrical resistivity, temperature coefficient of resistivity and melting point with in-

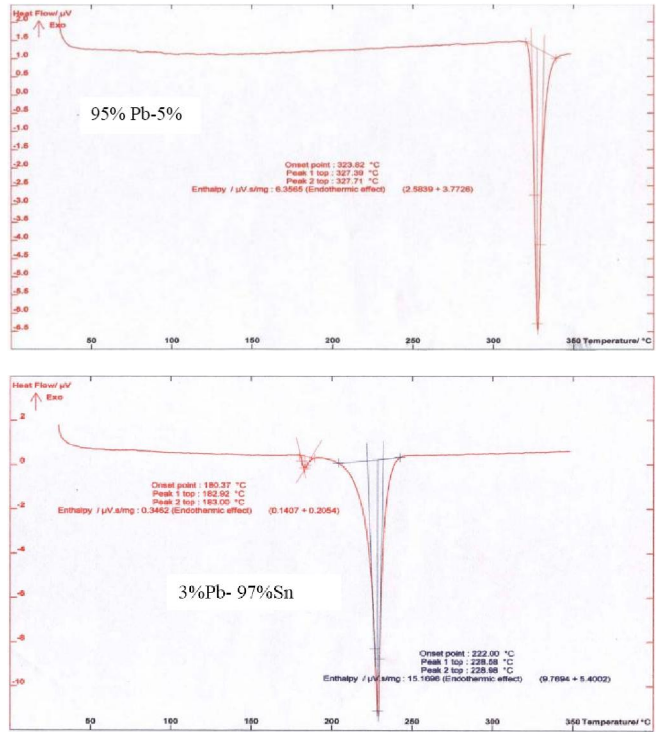


Figure 6 : Themographs of Pb-Sn alloys

creasing its elastic modulus. Tin- 3% lead rapidly solidified alloy have better electrical and mechanical properties with adequate melting point as a solder for electronic industrial applications.

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