

# Effects of Co and Cr particles additions on phase transformation temperature of a Pb-Sn based alloy

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The effects of Co and Cr particle additions on the phase transformation temperature of a Pb-Sn alloy were investigated. The microstructure, mechanical and phase characteristics of the samples were examined by optical microscopy, tensile test and DTA analysis techniques. The additions of Co and Cr particles were found to decrease the toughness and ductility of the Pb-Sn alloy. The melting temperature of the Pb-Sn alloy is increased by Co and Cr particles but, the phase transformation temperature is decreased. The results obtained indicate that the phase transformation temperature of Pb-Sn based alloy can be controlled by Co and Cr particles.

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## 1. Introduction

Pb-Sn alloys constitute a large group of the alloys, which can be melted at low temperatures. They are often used to form alloys with tin. Furthermore, these alloys are durable in different kinds of climate conditions, even in areas with active corrosive elements, such as soil, sea and industrial areas. Their resistance against acids proves especially useful and they are used successfully in acid production and in the fabrication of electrical and accumulator materials. Pb is not only used to develop the corrosion resistance of any alloy, but also to increase the range of brazing and to allow it to be submerged as sheet and wire [1]. Co additions increase the melting point and strength of Pb alloys and help it when it is being used in corrosive environments. Also, Co can be used to develop prosthesis tool and corrosion resistance. When Co is added to sintered carbides; it protects its hardness and prevents it going soft at high temperatures. It is mainly used in the fabrication of permanent magnet [1]. Pure Co is the main element of hardfacing alloys; It exists in two allotropes: a high-temperature  $\alpha$  with a FCC (face centred cubic) crystal structure, which is stable at high temperatures up to the melting point (1495 °C); and a low-temperature allotrope  $\epsilon$  with a HCP (hexagonal close packed) crystal structure, which is stable at temperatures below 417 °C [2-4]. However, a longstanding controversy exists as to the stability of the FCC allotrope. Several investigators believe that there is a second allotropic transformation of Co (fcc to hcp) at or near to the Curie temperature (1121 °C) [5, 6]. Also, its evidence has been present that the FCC phase is stable from 450 °C to at least 1223 °C [3, 7]. The  $\alpha \rightarrow \epsilon$  allotropic transformation in Co below 417 °C is often classified as a martensitic transformation [2]. The amount of  $\epsilon$  depends on purity and grain size; a fine grain size in pure Co prevents the  $\alpha \rightarrow \epsilon$ , reaction [8]. It has been found that though repeatedly melting it and performing

mechanical processes, phases or compounds such as PbCo or PbCr did not come into existence, as mentioned in Ref. [9].

In this study, the effects of Co and Cr particle addition on the phase transformation temperature, mechanical properties and microstructure of the Pb-Sn alloys are investigated using the differential thermal analysis (DTA) method, tensile tests, optical microscopy and density measurements.

## 2. Experimental details

The chemical compositions of the materials used in the study are given in Table 1. For metallographic investigations, S1, S2 and S3 samples in dimensions of  $\varnothing 15 \times 10$  mm were prepared using the mechanical alloying technique. Then; the prepared samples were polished with 220-1200 mesh SiC sandpaper and finished with a diamond paste up to the level of 0.1  $\mu\text{m}$ . Beraha solution [240 g sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ), 24 g lead acetate Pb ( $\text{CH}_3\text{COO}$ ) $_2 \cdot 3\text{H}_2\text{O}$ , 30 g citric acid ( $\text{C}_6\text{H}_8\text{O}_7 \cdot \text{H}_2\text{O}$ ), 1 l distilled water] at room temperature was used for etching for 30-60 s [10]. After being etched, image analysis was performed using the OM technique. In order to determine whether Co and Cr additions affected the mechanical properties of the samples (DIN 50125), strength tests were made using a Hounsfield type test device; with a load capacity of 50 KN. The density of the samples was measured using the Archimedes principle and phase transformation analysis was performed using a Setaram type DTA device, in an atmosphere of Ar gas with a heating speed of 10 °C/min. and a 400 °C oven regime.

Table 1 The chemical composition of samples.

Sample No	Sn	Cu	Co	Cr	Pb
S1	23.4	3.2	-	-	Balance
S2	23.1	3.4	5.1	-	Balance
S3	23.0	3.5	-	7.2	Balance

### 3. Results and discussion

Fig.1 shows the microstructures of samples S1, S2 and S3, respectively. In this figure, the white regions correspond to Pb-based oxides, the regions close to the colour violet have multiple phases, such as Pb-Sn-Cu, Cu-Sn, PbO, SnO and CuO, the regions close to green (black) and blue have  $\alpha$  phase, and red-yellowish or green-bluish regions have  $\beta$  phase [10]. The high ductility of parent material is decreased with the addition of Co and Cr particulates (Fig. 2).

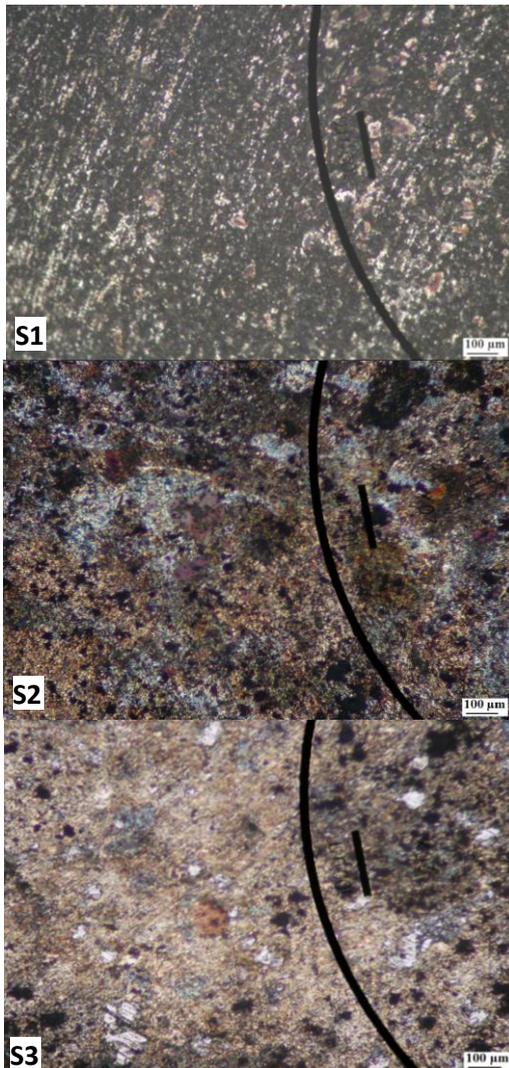


Fig.1. Optical microstructures of the samples (a) S1, (b) S2 and (c) S3.

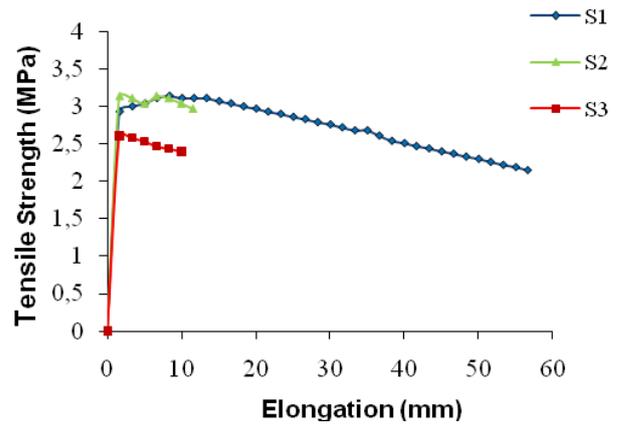


Fig.2. Strength-% Elongation diagram of S1, S2 and S3 samples.

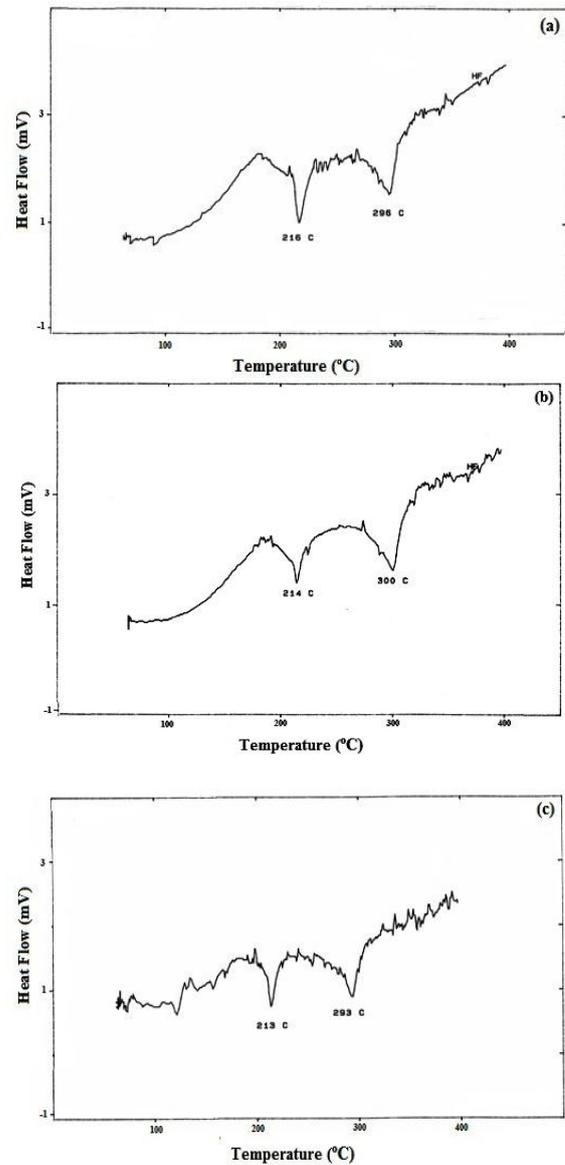


Fig.3. DTA curves obtained for the  $10^{\circ}\text{C min}^{-1}$  heating regime for the samples: (a) S1, (b) S2 and (c) S3.

Table 2 The tensile experiment results of samples.

Sample no	Symbols of samples	Tensile test (N/mm <sup>2</sup> )	Change length $\Delta l$ (mm)	Original cross-section area $A_0$ (mm <sup>2</sup> )	Finally cross-section area $A_1$ (mm <sup>2</sup> )	Reduction of cross-sectional area % $\psi$
S1	Pb-Sn-Cu	3.113	57	28.26	13.847	51.01
S2	Pb-Sn-Cu-Co	3.149	12	28.26	26.407	6.556
S3	Pb-Sn-Cu-Cr	2.618	10	28.26	26.407	6.556

The tensile test results are given in Table 2. Although the ductility and toughness of the samples decreased with addition of Co, the yield stress tended to increase. On the other hand, the addition of Cr showed similar results in terms of ductility and toughness of samples [9]. Co and Cr particulates were adequately segregated in the S2 and S3 samples, which were not enough uniformly distributed through the main body of the reinforced alloy. As the diffusion of Cr and Co particles in the main matrix did not happen very well, the toughness of the S2 and S3 samples decreased [11]. In addition, it can be seen that the hardness of these samples increased due to the Cu-Sn (Cu<sub>6</sub>Sn<sub>5</sub>) compounds and the Co-Cr elements [12,13]. The densities of samples were measured as 9.98 gr/cm<sup>3</sup>, 8.67 gr/cm<sup>3</sup> and 8.98 gr/cm<sup>3</sup> for the S1, S2 and S3 specimens, respectively. It was found that the intensity values of the samples decreased with the addition of Co and Cr. Looking at the DTA curves shown in Fig. 3 and the Pb-Sn equilibrium diagram [14], it can be seen that melting begins at 183 °C and completes at 200 °C in Pb-Sn alloy. When 3.2 wt.% copper is added to the samples, the melting temperature increases to 212 °C. Also, the phase transformation temperatures decreased from 216 °C to 214, 213 °C with the addition of Co and Cr. Also, the Cu<sub>6</sub>Sn<sub>5</sub> phase is composed in the  $\alpha+\beta$  (Pb+Sn) main matrix. On the other hand, the solid-liquid status transformation occurs at 296, 293 and 300 °C. The first point obtained from differential thermal analysis is between 210 - 216 °C in S1 (a). This point corresponds to the eutectic point in the Pb-Sn binary phase diagram and this was changed by 3-4 °C by the addition of Co and Cr elements. The second transformation point is the otectoidic transformation point of the Cu-Sn binary alloy; this point also decreases from 350 °C to 290 - 300 °C with the addition of Co and Cr elements [9, 15]. The high melting temperature of Co and Cr particles; which were added to S2 and S3 did not diffuse to the Pb-Sn alloy [11].

#### 4. Conclusions

The following conclusions could be drawn from this study:

The ductility of the material decreases with Co addition and, in turn, the toughness also decreases. Furthermore, the yielding strength strongly increased with Co addition. Cr addition decreased the ductility, toughness and the yielding strength of the material. Co and Cr additions decreased the densities of the samples. Although Co and Cr additions increase the eutectic temperature of the Pb-Sn alloy with Cu, the phase transformation temperatures of Pb-Sn decreased.

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