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A comparative analysis of microstructural features, tensile properties and wettability of hypoperitectic and peritectic Sn-Sb solder alloys

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ABSTRACT

Sn-Sb alloys are among the current alternatives for the development of alloys for high-temperature lead-free solders. The Sn-Sb alloys having 5.5 wt.% Sb or less are known to have good mechanical properties, and despite the quite low liquidus temperature have been considered adequate in the development of solder joints. The increase in the Sb content up to the limit of solubility in Sn at about 10 wt.% is supposed to be detrimental to the mechanical properties due to the extensive formation of an intermetallic compound. Investigations on the interrelation of microstructure of this alloy and the corresponding mechanical properties are fundamental to an appropriate evaluation of its application in solder joints. The present investigation analyses the relationship between microstructural features of the peritectic Sn-10 wt.% Sb alloy, solidified under a wide range of cooling rates, and the resulting mechanical properties. A cellular β-Sn matrix, typified by cellular spacings that decrease with the increase in the solidification cooling rate, and Sn_3Sb_2 particles are shown to characterize the alloy microstructure. The ultimate tensile strength is higher as compared with the corresponding values of the hypoperitectic Sn-5.5 wt.% Sb solder alloy, however the elongation is shown to decrease. A comparison with Bi-Ag alloys, considered good high temperature solders alternatives, has shown that the tensile properties of the Sn-10 wt.% Sb alloy, including elongation, are significantly higher. Wettability tests have been carried out and the experimental results, according to reports from the literature, are associated with good wettability.

1. Introduction

In the light of pressures to remove lead from electronics around the world, the lead-free manufacturing has demanded studies on new solder alloys to replace the traditional tin-lead alloys, which were the mainstay of the electronics industry in the last century. Not only yield production but also field reliability has been the challenging issues faced by various candidate alloys that hardly compete with lead-based alloys in terms of cost and technical benefits, such as low processing temperatures associated with appropriate mechanical properties. Each lead-free alloy has advantages and disadvantages i.e., none alloy is recognized to fit all demands, and in this sense each different alloy composition is suitable for niche applications [1–5]. A particular process, known as step soldering, involves solder alloys related to high temperature electronic devices (from 270 °C to 350 °C), in which multiple solders of successively lower melting points are used in consecutive joints, in order to preserve the integrity of earlier soldered joints [6–8]. This kind of technique employs mostly alloys far from eutectic compositions, but with higher melting temperatures, and aggregating as consequence, more complex transformations such as the peritectic one. The literature is scarce on information related to solder alloys comprising a peritectic reaction, denoting a gap to be explored in terms of characterization of microstructure and determination of properties.

The peritectic reaction is an invariant transformation in which a liquid phase (L) reacts with a solid phase (α) on cooling, giving rise to a second solid phase (β), i.e., $L + \alpha > \beta$. The solid (α) separate out from (L) at the peritectic temperature and must dissolve in L, and β must freeze out of L. Because the high cooling rates used in industrial processing, the completion of the equilibrium peritectic reaction is rarely observed, since β surrounds α and the peritectic reaction is stifled since L cannot reach α [9]. The literature reports works on peritectic alloys under fast cooling rates such as: ferrous [10–12] and non-ferrous alloys [13–16]. Regarding the soldering process, high cooling rates are

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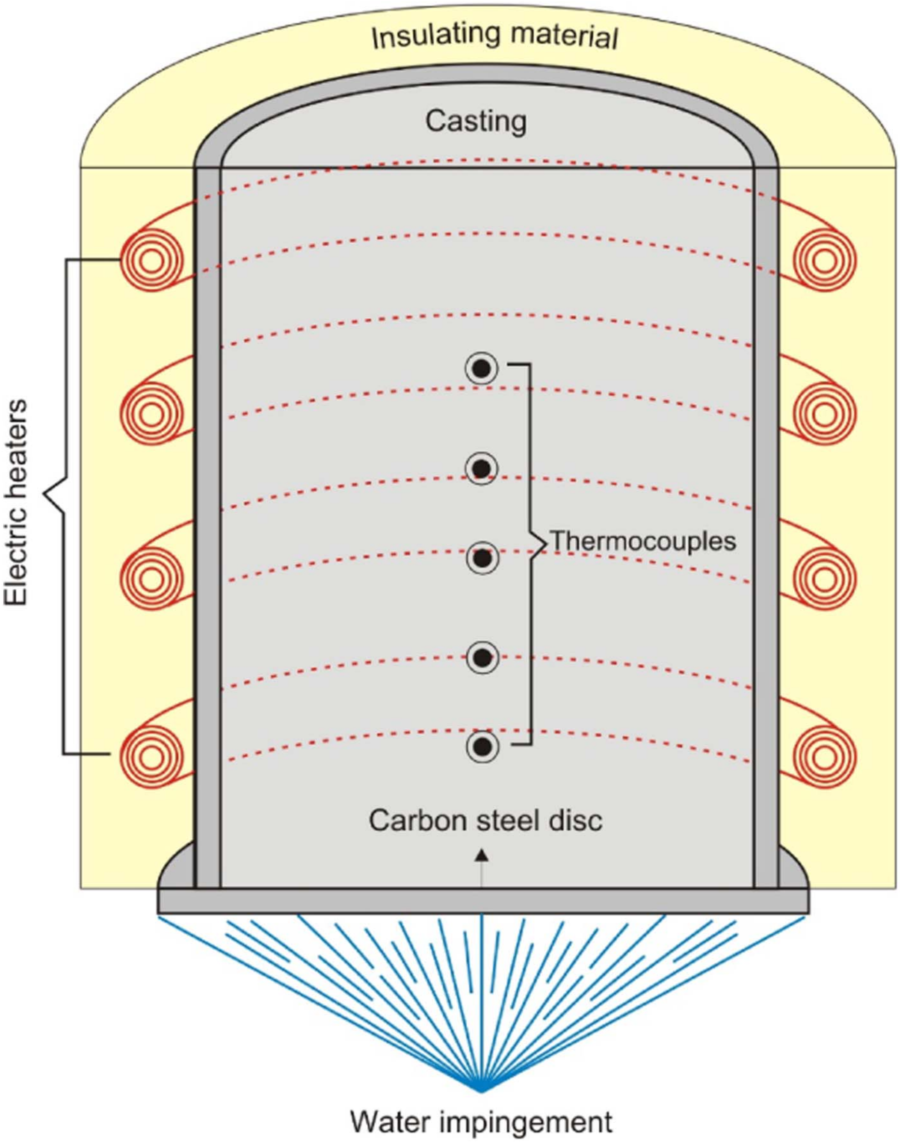

Fig. 1. Schematic representation of the solidification experimental setup.

Table 1
Chemical composition (wt.%) of metals used to prepare the Sn-10 wt.% Sb alloy.

Element	Pb	Fe	Sb	Sn	Cd	Ni	Cu	Bi	Zn	Si
Sn	0.0469	0.0081	0.0005	Balance	0.00001	0.0001	0.0047	0.0046	0.0001	–
Sb	0.215	0.075	Balance	–	–	0.034	0.034	–	–	0.009

inherent during solidification inducing the formation of metastable phases. The Sn-Cu [17] and Sn-Sb [18] alloys systems are practically the only binary tin-based alloy systems used in high temperature soldering that undergo peritectic reactions. There exists a broad literature related to alloys of the Sn-Cu system, although more concentrated in low temperature applications, because of its importance as base of ternary alloys such as Sn-Cu-Ni [19,20] and Sn-Ag-Cu alloys [21,22]. On the other hand, the same does not occur in similar extent to alloys of the Sn-Sb system, which deserve to be investigated in greater depth.

A peritectic reaction, L + Sn_3Sb_2 > Sn (β), occurs at the tin-rich part of the Sn-Sb binary phase diagram (243 °C), and from the peritectic composition the *liquidus* temperature (T_L) increases with increasing Sb content [7,23]. It is worth noting the existence of conflicting interpretation in the literature concerning the composition of the first solid phase to separate out from the liquid at the liquidus temperature (i.e. the intermetallic compound - IMC). The occurrence of either Sn_3Sb_2 or SnSb IMCs is reported in the literature. Some works affirm that Sn_3Sb_2 decomposes into SnSb and β below 242 °C [24,25]. The most promising Sn-Sb alloys for soldering are the Sn-5wt.%Sb, which has a near peritectic composition, and the Sn-10 wt.% Sb alloy, the peritectic composition. Kim and collaborators [6] have obtained samples of Sn-5 wt.% Sb and Sn-10wt.%Sb alloys solidified in air and performed characterization of the resulting phases using X-ray diffraction and energy-dispersive X-ray analyses. For both alloys, a β-Sn matrix and β-SbSn were shown to constitute the microstructure. Recently, Yilmaz and collaborators using the same characterization techniques, found the same phases in a Sn-10.2 wt.% Sb alloy directionally solidified under steady-state conditions [26]. The Sn-5.5wt.%Sb alloy was reported to have both good mechanical strength and creep properties, which are fundamental to pin-attachment reliability. Dias et al. [18] established