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Short Communication

Effect of substrate surface texture and flux coating on the evolution of microstructure during solidification of lead free Sn–3.5Ag solder alloy

K. Narayan Prabhu *, Rantej Bali, Rajat Ranjan

Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, P.O. Srinivasnagar 575 025, Surathkal, India

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Abstract

The microstructure of a solidifying lead free Sn–3.5Ag solder alloy is found to be highly sensitive to the surface condition of the copper substrate. A transition from lamellar to fine fibrous eutectic structure is observed as the surface condition of the substrate is altered by increasing the surface roughness and application of flux. This is attributed to lowering of interfacial tension and improved wetting of the solidifying solder on the substrate material leading to a better contact at the metal/substrate interface. The results also indicated the importance of surface texture of the substrate and the application of the flux to the quality of the solder/substrate joint.

Keywords: Solder; Solidification; Substrate; Surface texture; Microstructure

1. Introduction

The difficulties inherent in the solidification of most metals are present in the case of solder solidification as well. For example, many solder alloys exhibit shrinkage upon solidification and cooling, and this leads to the formation of an air gap between the solidifying metal and the base metal surface [1]. This will strongly influence the evolution of microstructure in the solidified alloy and also reduce the strength of the joint by limiting the contact between the solder and the base metal. The formation of an air gap or a nonconforming contact at the interface during soldering depends upon the ability of the molten solder alloy to flow over and wet the base metal. This can be influenced by several parameters like the substrate material, surface roughness of the substrate metal, composition of the solder alloy, type of flux used and also the temperature of the liquid solder [1–4].

Currently there is an increasing trend to use lead-free solders in microelectronic devices mainly for better environmental protection, increased recycling and easy disposal of electronic devices. Sn–3.5Ag alloy is one of the promising lead free solder alloys. Like eutectic Sn–Pb, Sn–3.5Ag is quite strong even at 100 °C [5]. However, the wetting of this alloy compared with the eutectic Pb–Sn solder alloys is poor. The wetting behaviour of the alloy influences the cooling rate significantly and this is the most critical soldering parameter that affects the solidified microstructure. The aim of the present work is to study the effect of the surface texture of the substrate and the use of flux coating on the microstructure evolved during solidification of a lead free Sn–3.5Ag solder alloy.

2. Experimental method

Fig. 1 shows the schematic sketch of the experimental set-up used to carryout upward solidification of the solder alloy against circular copper chills of 25 mm diameter and 10 mm thickness. The following are the

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* Corresponding author. Tel.: +91-824-2475984x256; fax: +91-824-2492794.
E-mail address: prabhukn_2002@yahoo.co.in (K.N. Prabhu).

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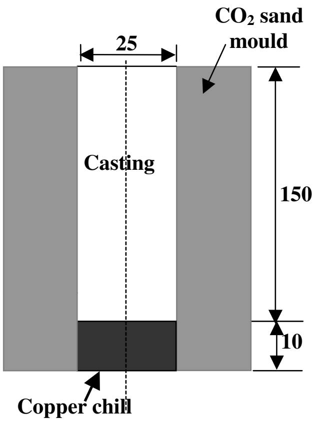

All dimensions are in mm

Fig. 1. Schematic sketch of the experimental set-up.

surface conditions of the substrate (copper chill) used in the present investigation.

(1) Mirror finish ($R_a = 1.3$ µm, $R_z = 0.9$ µm, $R_y = 0.9$ µm) chill surface without flux coating
(2) Mirror finish $R_a = 1.3$ µm, $R_z = 0.9$ µm, $R_y = 0.9$ µm) chill surface with $ZnCl_2$ flux coating
(3) Rough finish ($R_a = 1.6$ µm, $R_z = 3.1$ µm, $R_y = 6.3$ µm) chill surface without flux coating
(4) Rough finish ($R_a = 1.6$ µm, $R_z = 3.1$ µm, $R_y = 6.3$ µm) chill surface with $ZnCl_2$ flux coating

The pouring temperature of the alloy was nearly 260 °C for all the experiments. After solidification, castings were sectioned and the casting specimens near the chill surface are subjected to metallographic examination.

3. Results and discussion

Fig. 2(a) and (b) shows the microstructures of the casting at 5 mm from the chill obtained with smooth and rough substrate surfaces without a flux coating. Fig. 3(a) and (b) shows the corresponding microstructures when flux coating is applied on the copper substrate. A coarse lamellar eutectic microstructure showing the intermetallic Ag_3Sn in the form of needles is obtained with a smooth mirror finished chill without any flux coating on its surface. When the chill surface is smooth and no coating is applied, the oxide film present on the substrate surface impedes the heat transfer from the molten metal to the chill. The slower cooling of the solidifying alloy results in coarse lamellar structure. On the other hand, a rough chill surface with a flux coating makes the Ag_3Sn precipitates finer and more spherical. A rough surface is associated with a more contact area and when flux coating is applied the ability of the molten metal to wet the surface is enhanced and the interfacial tension is decreased. Another possibility is that the asperities of the rough surface might rupture the oxide film on the solidifying alloy and contribute to improved wetting of the liquid metal with the substrate. The lowering of the interfacial tension and improved wetting would increase the thermal contact conductance at the metal/substrate interface leading to enhanced heat transfer rates from the solidifying alloy to the metal substrate. With increase in cooling rates, the eutectic structure loses its lamellar character and a fine dispersion of Ag_3Sn precipitates within a Sn matrix is obtained. Dendritic globules of Sn are observed for castings solidified against both smooth and rough surfaces coated with $ZnCl_2$ flux material.

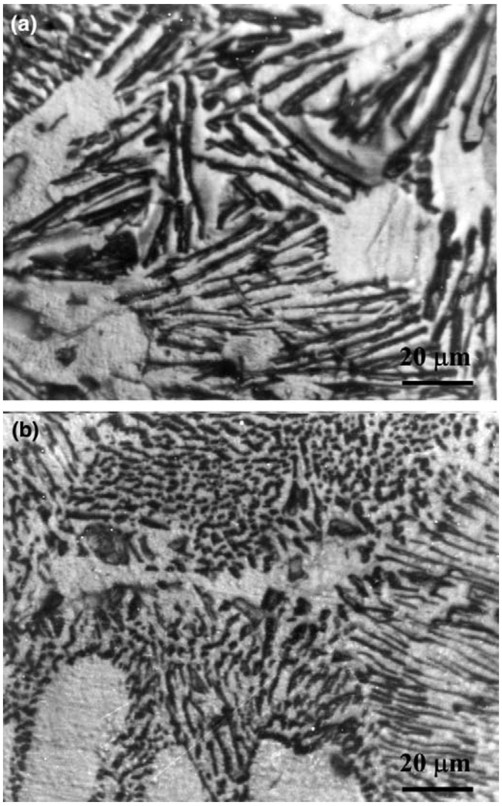

Fig. 2. Microstructures of Sn–3.5Ag alloy at 5 mm from the solder/copper substrate interface for (a) smooth and (b) rough surfaces without flux coating.

The transition in the microstructure morphology is very similar to the modification melt treatment of Al–Si eutectic alloys. However, unlike in the case of Al–Si alloys, there is no necessity of addition of a chemical modifier and the change in the morphology of the eutectic structure is brought about by an increase in the growth rate. The microstructure is modified simply altering the surface texture of the substrate from a smooth to a rough finish and the application of a flux coating on the surface of the substrate.

The microstructure evolved during solidification against various substrate surface conditions had a significant effect on the quality of the joint at the solder/substrate interface. For example, with a smooth sur-

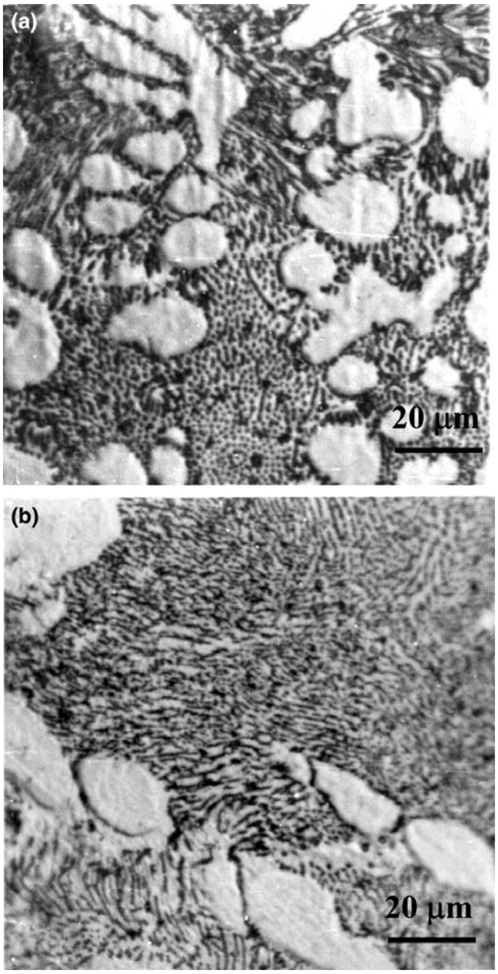

Fig. 3. Microstructures of Sn–3.5Ag alloy at 5 mm from the solder/copper substrate interface for (a) smooth and (b) rough surfaces with flux coating.

faced chill without coating, no joint formation is observed. When the surface is made rough, a joint is formed at the metal/substrate interface but is found to be weak. A good joint is formed with a smooth surface with a flux coating but is easily separated by hammering. However, when a flux coating is applied on the rough surface a strong joint is obtained and could not easily be separated despite heavy hammering.

4. Conclusions

The evolution of the microstructure of a eutectic Sn–Ag alloy solidifying against a metallic substrate is highly sensitive to the surface texture of the substrate and the application of flux coating on the substrate surface. The use of flux and increased roughness of the substrate seem to increase the cooling rate of the solidifying solder alloy. A transition from lamellar to a fine fibrous eutectic microstructure is observed as the surface condition of the substrate is altered from a smooth to a rough texture with a flux applied on its surface. This transition in the microstructure is found to be accompanied by an improvement in the quality of the joint at the solder/substrate interface.

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