Materials and Design 32 (2011) 4763–4772

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Electrochemical behavior of a lead-free SnAg solder alloy affected by the microstructure array

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ARTICLE INFO

Article history:
Received 7 April 2011
Accepted 17 June 2011
Available online 24 June 2011

Keywords:
A. Non-ferrous metals and alloys
C. Casting
E. Corrosion

ABSTRACT

The aim of this study is to evaluate the electrochemical corrosion behavior of a Sn–Ag solder alloy in a 0.5 M NaCl solution at 25 °C as a function of microstructural characteristics. Different microstructure morphologies, which can be found in Sn–Ag solder joints and that are imposed by the local solidification cooling rate, are evaluated and correlated to the resulting scale of the dendritic matrix and the morphology of the Ag_3Sn intermetallic compound. Cylindrical metallic molds at two different initial temperatures were employed permitting the effect of 0.15 °C/s and 0.02 °C/s cooling rates on the microstructure pattern to be experimentally examined. Electrochemical impedance spectroscopy (EIS) diagrams, potentiodynamic polarization curves and an equivalent circuit analysis were used to evaluate the electrochemical parameters. It was found that higher cooling rates during solidification are associated with fine dendritic arrays and a mixture of spheroids and fiber-like Ag_3Sn particles which result in better corrosion resistance than coarse dendrite arrays associated with a mixture of fibers and plate-like Ag_3Sn morphologies which result from very slow cooling rates.

1. Introduction

The traditional Sn–Pb eutectic solder alloy has been widely used in electronic and communication components in the last decades. However, the increasingly environmental and health concerns over the toxicity of lead combined with strict legislation to ban the use of lead-based solders have provided an inevitable driving force for the development of lead-free solder alloys [1–3]. In this context, alternative binary alloys have been examined as replacements for Sn–Pb solders, such as near-eutectic Sn–Ag, Sn–Cu, and Sn–Zn alloys. However, ternaries (SnAgCu, SnZnAg, Sn–Zn–In, etc.) and even quaternary alloys (SnZnAgAl, SnAgBiCu, SnInAgSb) have also been studied as candidates for lead-free solders [2–7]. The Sn–Ag solder alloys are among the most promising candidates due to their compatible properties with the Sn–Pb solder [8,9].

Typical hypoeutectic Sn–Ag alloys have as-cast microstructures formed by a Sn-rich dendritic matrix and a eutectic mixture of a Sn-rich phase and intermetallic Ag_3Sn particles located in the interdendritic regions. Commercially as-cast SnAgCu alloys (SAC) present additionally the Cu_6Sn_5 intermetallics, which is also located in the interdendritic region, as previously reported in a number of studies [10–13]. It has been reported in a literature survey that three different morphologies of Ag_3Sn particles can be formed during solidification depending on the applied cooling rate [13–18]. High cooling rates are associated with spheroid-like Ag_3Sn particles while very slowly-cooled Sn–Ag samples have Ag_3Sn particles which are characterized by a mixture of plate-like and fiber-like morphologies. It has also been reported that different cooling rates [14,24] and the alloy Ag content [14] can strongly affect the morphology of Ag_3Sn particles.

The microstructural morphological array of Sn–Ag solder alloys, including the scale of the dendritic Sn-rich matrix and the size, morphology and distribution of the Ag_3Sn particles in the interdendritic region has an important role on the resulting mechanical behavior of solder joints. For instance, brittle Ag_3Sn particles may lead to serious problems under stressed conditions at service for printed wiring boards [17–19]. It has also been reported that large Ag_3Sn platelets can exhibit a mixture of both ductile and brittle fractures while fine platelets would strengthen the solder matrix [18]. The resulting Sn–Ag microstructure has also great effect upon other properties, such as physical, electrical, and oxidation and electrochemical behavior of the solder joint. In this sense, it would be interesting to accurately characterize the intermetallic Ag_3Sn particles and the Sn-rich matrix as a function of the influent parameters during cooling in order to attain guidelines with a view to predetermining a desired performance in terms of the required final properties of solder joints.

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0261-3069/$ - see front matter
doi:10.1016/j.matdes.2011.06.032