

EFFECT OF AGING ON MECHANICAL PROPERTIES OF Sn-Cu-Fe-Bi SOLDER ALLOY

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ABSTRACT

The current work study the effect of Fe and Bi addition, 0.05wt% Fe and 1wt% or 2wt% Bi, on the microstructural and mechanical properties of the Sn-0.7Cu (SC07) solder alloy. The addition of Fe and Bi to SC07 increased ultimate tensile strength (UTS) and yield strength and decreased the total elongation which is related to solid-solution and precipitation strengthening effects by Bi in the Sn-rich phase. Minor addition of Fe does not have considerable effect on mechanical properties. Scanning electron microscopy (FESEM) and energy dispersive X-ray (EDX) showed that Bi strengthen solder by scattering in the bulk of SC07-Fe solder alloy, thereby increased β -Sn and degenerated Cu₆Sn₅ into a chain-like arrangement. After aging due to IMCs coarsening UTS and yield strength decreased for SC07 and SC07-Fe. Total elongation for SC07 and SC07-Fe increased. However, for sample with Bi, UTS, Yield strength and total elongation are approximately constant, because Bi prevent the Cu and Sn to interact with each other, therefore spheroidization and growth of IMCs slowed down and decreased the rate of IMCs coarsening.

Keywords: Sn-Cu solder; Bi and Fe additives; Microstructural properties; Mechanical properties; Aging

INTRODUCTION

The eutectic Sn-Pb solder has been a dominant alloy in electronic application [1-3]. However, Pb-free solders has been developed due to the health and environmental concerns for toxicity of Pb [4]. The eutectic Sn-0.7Cu solder alloy with superior properties such as: low-cost, comparable electrical performance, preventing dissolution of Cu substrate and conveniently is considered proper candidate for wave soldering in electronic application [5]. However, microelectronic solders based on Sn-Cu are mostly

exposed to microstructural roughening during usage or storage due to the coarsening of Cu₆Sn₅ IMC particles. In addition, the melting point of Sn-Cu solders are relatively high (~227°C) in compare to the Sn-Pb solder alloy (183°C) [6, 7]. Some alloying elements, such as Ni, Co, Ce, Fe, Ag, Sb and Zn [8-14] have been added to Sn-based solder alloys to reduce melting point and improve the microstructural and mechanical properties of the solder alloys. The present work studies dual addition of Fe and Bi to the Sn-0.7Cu solder alloy to investigate their effect on IMCs growth suppression and stabilizing mechanical properties after high temperature aging.

Previous research on Sn based solder showed that doping Fe increased its yield strength and UTS, and decreased elongation[15]. On the other hand, Fe improved drop impact reliability and also stabilized the mechanical properties of solder with aging[16]. Furthermore, Fe is able to suppress formation of Kirkendall voids [17].

The Bi addition significantly increase the ultimate tensile strength (UTS) of solders, because of a solid-solution hardening mechanism which make solder strong and brittle. Also, Bi decrease melting temperature [18].

In previous work, 0.05wt%Fe and Bi were added together to the low Ag solder, SAC105, to investigate the effect of these two elements on the bulk alloy microstructure, tensile and thermal properties. 0.05wt%Fe added to SAC105 because by increasing Fe more than 0.1wt% it makes large FeSn₂ intermetallic in bulk of solder which deteriorate mechanical properties [19]. Also selected 1 and 2wt% Bi to add to SAC105 because Liu et al. [20] showed that more than 3wt% Bi make solder too brittle. The present study investigates the effect of aging at 125 °C for 30 days or at 180 °C for 1 day on mechanical properties of SC07-0.05Fe-(1or 2) Bi solder alloys.

EXPERIMENTAL

This study used Sn-0.7Cu (SC07), Sn-0.7Cu-0.05Fe-1Bi (SC07-Fe-1Bi), and Sn-0.7Cu-0.05Fe- 2Bi (SC07-Fe-2Bi) bulk solder specimens. The dimension of dog bone samples were 5.0 mm thick × 5.0 mm wide×21 mm long.

Samples kept in oven at 125 °C for 30 days or at 180 °C for 1 day for aging. Universal testing machine (Instron5569A) utilized to measure tensile properties. A 10 mm extensometer was used for more accurate results. The tensile properties were obtained by averaging the test data after repeating test for five samples under same testing condition. Tensile tests were done under a strain rate of 10^{-3} s^{-1} at 25 °C to investigate the effects of added Fe and Bi on yield stress, ultimate tensile strength (UTS), and elongation.

A field-emission scanning electron microscope (FESEM; FEI Helios NanoLab 650) with a concentric backscatter detector (CBS) was used to take backscatter electron imaging and examine the microstructures. Also, energy dispersive X-ray spectroscopy

(EDX) and X-ray Diffraction (XRD) were utilized to find IMCs compositions. samples were prepared by dicing, resin molding, grinding and polishing for microstructure analysis. The samples were ground with SiC papers (#800, #1200, #2400, #4000) and then polished with a 3 μm diamond and a 0.04 μm colloidal silica suspension.

RESULTS AND DISCUSSION

Mechanical Properties

The mechanical properties of solder alloys include yield stress, ultimate tensile strength (UTS), and total elongation for as cast, aged at 125 °C for 30-days and aged at 180 °C for 1-day solder alloys are shown and compared in Figure 1. Aging at 180 °C for 1-day determine solders properties in automobile application. The current work focus on aging, at 125 °C for 30-days which is more common in electronic application.

For as cast samples, adding Fe to SC07 does not have considerable effect on UTS, yield strength and total elongation of SC07. But, by adding Bi to SC07-Fe UTS and yield strength increased whereas total elongation decreased. It is considered that Bi solutes in the Sn phase and causes solid solution hardening of the Sn phase. The dissolution of Bi atoms in the β -Sn lattice distort the latter, thereby causing a local stress fields that act as a barrier to the mobility of dislocations which in turn make the solder exhibit higher yield strength and UTS.

After SC07 aged at 125°C for 30 days UTS decreased from 27MPa to 20 MPa and yield strength decreased from 16.7MPa to 14MPa. Adding Fe does not have considerable effect on these properties. Total elongation for SC07 and SC07-Fe increased after aging, because the number of second phase decreased, therefore total elongation increased slightly. But UTS, Yield strength and total elongation for sample with Bi are approximately constant. Because Bi prevent the Cu and Sn to interact with each other, therefore spheroidization and growth of IMCs after aging slowed down and decreased the rate of IMCs coarsening.

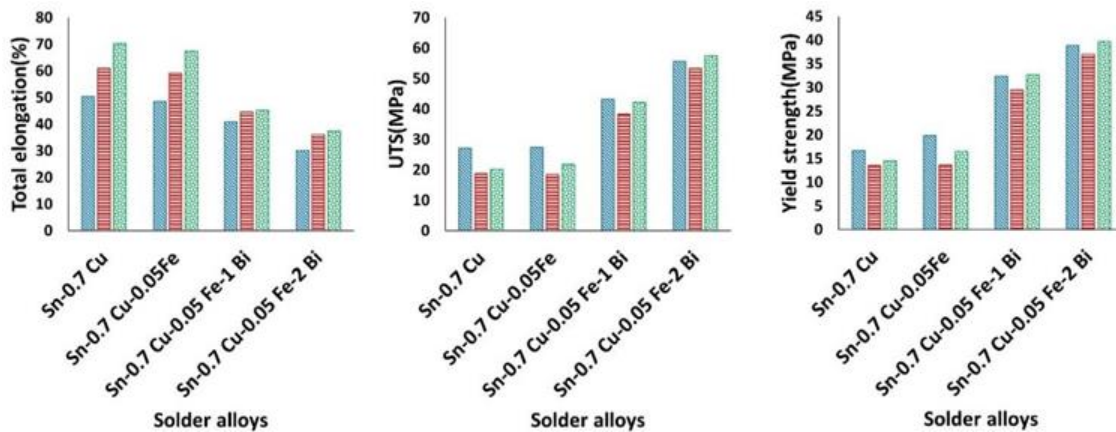


Figure 1: Mechanical properties of solder alloys

Microstructure properties

The FESEM micrographs of the as-cast and Aged microstructures of the SC07 and 0.05 wt.% Fe-added SC07 solder alloys are illustrated in Figure 2a, b, c and d. The composition of IMC particles in the two samples was confirmed by EDX and XRD analyses, as shown in Figure 2. The microstructures of the as cast solder consist of primary β -Sn dendrites and thick interdendritic regions consisting of Cu_6Sn_5 IMC particles dispersed within a Sn-rich matrix. It is seen that the addition of 0.05 wt.% Fe does not change the type of IMC particles. However, it leads to form few FeSn_2 IMC particles in the interdendritic regions. Because of the low solubility of Fe in the β -Sn most of the Fe precipitates as the FeSn_2 phase or in the eutectic regions [12].

It is observed for SC07 after aging, Figure 2b, the growth and spheroidization of Cu_6Sn_5 controlled by Gibbs–Thomson effect[21]. The surface free energy of the intermetallic phase decrease as result of the spheroidization and growth of Cu_6Sn_5 . The interface of Cu_6Sn_5 and Sn matrix prepare a heterogeneous region for the interaction between Cu and Sn. The Cu dissolved in Sn-rich phase and resulted in the growth of Cu_6Sn_5 [16]. It illustrates that Cu and Sn segregates at the surrounding of the Cu_6Sn_5 intermetallic phase and then forms the new intermetallic phase at the determined concentration. This procedure led to the growth of IMCs[22].

For SC07-Fe after aging, Figure 2d the combined analysis of atomic radii and electronegativity which is known as the Darken–Gurry ellipse used to predict elements that would dissolve in solid solution [23]. Fe falls inside the Darken-Gurry ellipse for substitution in place of Cu. Therefore, Fe can partially substitute into the Cu_6Sn_5 IMC particles. Fe atoms have -0.31% mismatch with Cu atoms. This partial substitution might produce increased lattice strain in the Cu_6Sn_5 IMC particles and reduce the vacancy diffusion rate. Thus, it decrease microstructure coarsening rate [24].

Due to the coarsening of IMCs yield strength and UTS decreased for SC07 after aging. For SC07- Fe the trend is same for yield strength and UTS, however because of Fe they drop less in compare to SC07. Figure 2e and g and shows the FESEM micrographs of the as-cast microstructures of the Fe-added SC07 solder alloy containing 1 and 2 wt.% Bi respectively. The addition of Bi also does not change the type of IMC particles. However, Bi leads to a progressive degeneration in the interdendritic regions and a significant refinement in the primary β -Sn dendrites. The Cu_6Sn_5 IMCs become less-packed and its amount significantly decreases. Remarkably, the network-like eutectic regions degenerated into a chain-like arrangement. It is therefore supposed that Bi super-saturated dissolved in the primary β -Sn phase and hence the microstructure of the Bi containing solder alloys is composed of β -Sn phase and Cu-Sn IMC. This can be attributed to the high solubility of Bi in Sn as the solid solubility limit of Bi in Sn at 120°C is below 3% [25]. The addition of Bi results in a lower area fraction of the eutectic Cu_6Sn_5 IMC as well as a higher area fraction of the β -Sn dendrites. The correlation between microstructural characteristics and its mechanical performance are

obvious. Therefore, any change in the microstructural properties of an alloy will affect its mechanical performance.

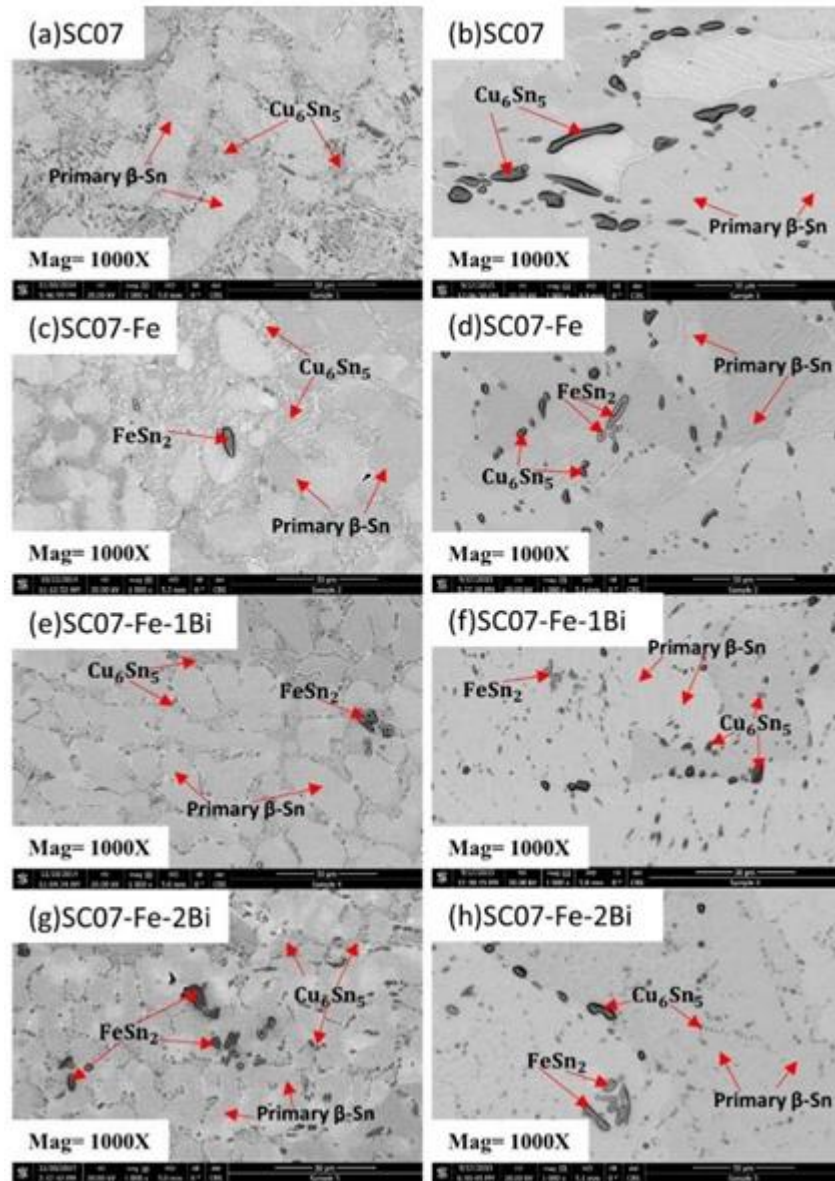


Figure 2: a,c,e, and g are FESEM results for as cast solder. b,d,f and h are FESEM results after aging at 125°C for 30 days

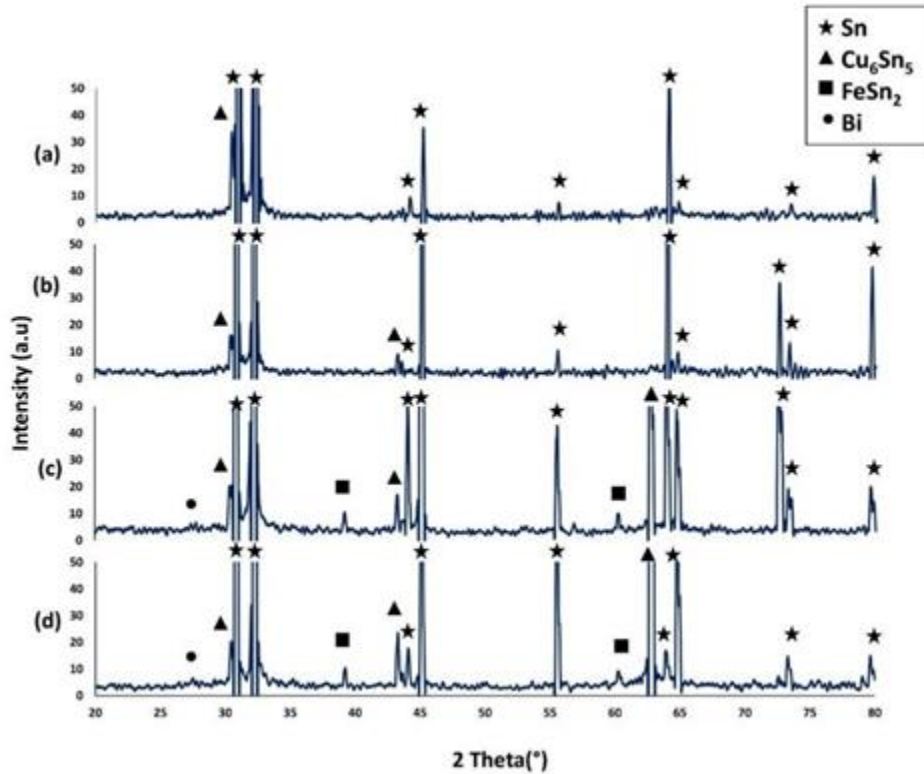


Figure 3: XRD result: (a) SC07, (b) SC07-Fe, (c) SC07-Fe-1Bi, and (d) SC07-Fe-2Bi solders

After aging, Bi prevented coarsening of IMCs. The existence of Bi within the β -Sn matrix reduce the activity of Sn involved in the chemical reaction between Sn and Cu during the solidification and hence reduces the amount of Cu_6Sn_5 IMC particles. Total elongation for SC07 and SC07-Fe increased because the number of IMCs decreased after aging as it is clear in Figure 2. Sn is considered to be soft due to its metallic bonding, whereas Cu_6Sn_5 IMCs are hard particles due to the strong covalent bonding of these IMCs, it would seem that an increase in the amount of Sn and decrease in the amount of Cu_6Sn_5 in the present study would make the solder more ductile. However, for SC07-Fe-1or2 Bi samples total elongation increased a little, which is related to the solid solution hardening mechanism of Bi that make solder strong and brittle.

CONCLUSION

By aging at 125°C for 30 days UTS and Yield strength for SC07 and SC07-Fe decreased. Total elongation for SC07 and SC07-Fe increased after aging. Also, partially substitution of Fe in Cu_6Sn_5 decreased microstructure coarsening rate. For samples with Bi, UTS, Yield strength and total elongation after aging are approximately constant, just slightly changed, because on the one hand Bi prevent the Cu and Sn to interact with

each other, therefore the rate of IMCs coarsening decreased. On the other hand, Bi make alloys strong and brittle as a result of solid solution hardening.

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