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Micromechanical properties of solder joint Sn3.0Ag0.5Cu on Electroless Nickel immersion gold (ENIG) using Nanoindentation approach

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ABSTRACT

This study explores the effect of high temperature storage (HTS) on micromechanical properties of solder joint Sn3.0Ag0.5Cu (SAC 305) on Electroless Nickel Immersion Gold (ENIG) surface. The micromechanical properties of SAC305/ENIG were measured using nanoindentation approach. The samples were stored in temperature of 180 °C at different time period from 200 hours up to 1000 hours. It was then followed by indentation made on the solder cross section using Berkovich diamond tip of nanoindenter machine. The findings of this study showed an increasing trend of maximum and plastic depth with the HTS time. It was also found that the hardness and reduce modulus of solder decreased as the HTS period lengthened with an exception at 400 hours HTS, where the reduced modulus surged to a higher value. The plasticity and elasticity-associated properties has become more prominent as the HTS time lengthened. These findings suggested that by using nanoindentation approach, has diverse applications especially accessing the micromechanical properties of solder joints.

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1. Introduction

In recent decades, lead free solders have undergone a flurry of interest in research due to new worldwide health regulations. As a result, Sn-based lead free solder alloys such as Sn-Ag, Sn-Cu and Sn-Ag-Cu have been used to substitute the Sn-Pb solder alloys (Osorio et al., 2011). Amongst the Sn-Ag-Cu solder alloy family, Sn96.5Cu3.0Ag0.5 (SAC305) is favourable due to its properties such as better ductility, superior strength and fatigue resistance (Plookphol et al., 2011).

Printed circuit board (PCB) with surfaced finishes are widely used in the electronics industry. The surface finish is usually used to protect the circuit from corrosion and provide solderable surface for soldering process for the components to attach on the PCB. There are various type of surface finish such as immersion tin (ImSn) (Chen at al., 2007), organic solderability preservatives (OSP) (Liu et al., 2015), electroless nickel immersion gold (ENIG) (Liu et al., 2016, Arshad et al., 2006) and electroless nickel-electroless palladium-immersion gold (ENEPIG) (Tseng et al., 2013) and etc. This study focuses on ENIG because of its various advantages such as Pb free, low cost, anti-oxidation and provides good solderability.

Reliability is attractive for industrial practice. Typical reliability studies involve the study of mechanical properties. Mechanical properties can be obtained by various methods such as tensile test, pull test, shear test, and impact test. However, in this occasion, we used nanoindentation approach to study the micromechanical properties. This method has many advantages such as capability to analyse localise hardness, elastic and plastic properties of the materials (Hu and Zongjin, 2015). In this paper, we report the micromechanical properties of SAC305 on ENIG surface finished using nanoindentation approach. High temperature storage test is used in order to observe the micromechanical properties response.

2. Materials and methods

In this study, lead free solder paste, Sn96.5Ag3.0Cu (SAC305) and a standard test board with dimensions of 11 cm x 10 cm x 0.2 cm were supplied by Redring Solder (M) Sdn. Bhd. The test board was coated with Electroless Nickel Immersion Gold (ENIG). A stencil was used to print the solder

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paste on the ENIG test board. The printed solder paste was then placed in a reflow oven (Madell Technology Corporation) for reflow soldering process at 215 °C for 8 second. Next, the soldered test board cooled at room temperature after reflow process. Subsequently, the test board was cut into small pieces using a diamond cutter blade machine, approximately about 0.5 cm x 0.4 cm x 0.2 cm dimensions and containing a few soldered pitches. For high temperature storage (HTS) test, the samples were placed in an oven at 180 °C for 200, 400, 600, 800 and 1000 hours. For nanoindentation, the samples were diagonally cross section cold mounted using epoxy resin. The cold mounted samples were then ground using silicon carbide (SiC) abrasive paper, starting from 800, 1000 and 1200-grit and polished using diamonds sprays of 1 µm.

The nanoindentation test was performed by using Micro Materials Nanotest™ indenter equipped with a pointed indenter, Berkovich diamond tip. Nanoindentation test was conducted at room temperature and the indentation was made on the middle of the solder. A constant of loading and unloading rate of 0.5 mN/s was applied to the sample surface until maximum load of 10 mN was reached. The dwell time is 30 second at the maximum load followed by the unloading process. The thermal drift correction is a 60 second hold time was applied at 90% unloading. The hardness and the reduced Young's modulus are obtained from the load-depth data which based from Oliver and Pharr method (Oliver and Pharr, 2004). Fig. 1(a) shows the schematic illustration represents the load and unloads process during nanoindentation test and Fig. 1(b) shows plot of load-displacement curve from nanoindentation test.

The depth between indenter and sample, $h_c = h_{max} - h_s$ is calculated as follow:

$$h_c = h_{max} - \epsilon \frac{p_{max}}{S} \quad (1)$$

Where P_{max} is maximum load applied to the sample. The contact area, A is:

$$A = F(h_c) \quad (2)$$

Where $F\ (h_c)$ is the area of function to describe the projected area A; The hardness is then can be determine as:

$$H = \frac{P_{max}}{A} \quad (3)$$

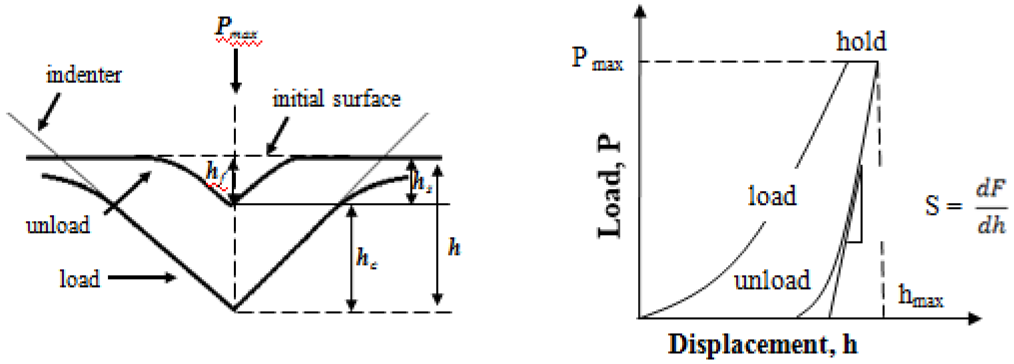
The reduce modulus, E_r is calculated as follow:

$$E_r = \frac{S\sqrt{\pi}}{\sqrt{A_c}} \quad (4)$$

Where S is the contact stiffness which corresponding to the slope of unloading curve (Fig. 1b), and A_c is the area of contact. E_r is also given by:

$$\frac{1}{E_r} = \frac{(1-v_s^2)}{E_s} + \frac{(1-v_i^2)}{E_i} \quad (5)$$

Where E_s and E_i are Poisson's ratio of the sample and the indenter, respectively, $V_s$and V_i are the Young's modulus of the sample and the indenter. The Poisson's ratio and Young's modulusof indenter used in this work is 0.07 and 1140 GPa, respectively.



(a) (b)

Fig. 1: (a) Schematic illustration represents the load and unloads process during nanoindentation test and (b) plot of load-displacement curve from nanoindentation test

3. Results and discussion

In this study, we use the nanoindentation approach to study the micromechanical properties of SAC305 on ENIG surface finished after being subjected to high temperature storage at 180 °C for 200 hours up to 1000 hours. This nanoindentation test is a special method to study the localized micromechanical properties (Zulkifli et al., 2013). It provides almost similar information to stress-strain test using depth-sensing approach. The information that can be obtained from nanoindentation test is including plastic depth, elastic recovery parameter, hardness, reduced modulus, plastic work and elastic work. Fig. 2 is the load versus depth for indentation of SAC305/ENIG subjected to HTS. It is clearly seen different load-depth curve was obtained for SAC305/ENIG showing that the HTS has affect the solder joint properties.

Variation of maximum depth and plastic depth is shown in Fig. 3. For sample without HTS, the maximum depth is 1300 nm and increased up to 1590 nm as the HTS prolonged to 1000 hours. This indicates that as the solder exposed to longer HTS, deeper penetration of indenter were reached. The plastic depth has shown similar trending, 1287 nm for 0 hour and increased to 1574 nm. However, it is shown that the plastic depth is less than the maximum depth. It is shown that the plastic behaviour of the solder is more dominance compared to elastic behaviour. The finding is consistent with the hardness result in Fig. 4, showing the hardness is decreased with HTS time, from 0.26 GPa for 0 hour to 0.17 GPa for 1000 hours, indicating that the solder become softer after subjected to HTS. Similar results were reported by Dompierre et al. (2011), the hardness of the solder were decreased with the ageing time. However, contradictory result for reduced modulus is obtained, 82.91 GPa for 0 hour is then fluctuated to 79.73 GPa for 200 hours and increased to 97.50 This suggests that hardness value is a reflection to micro plastic properties while the reduced modulus is associated to the elastic properties of the solder.

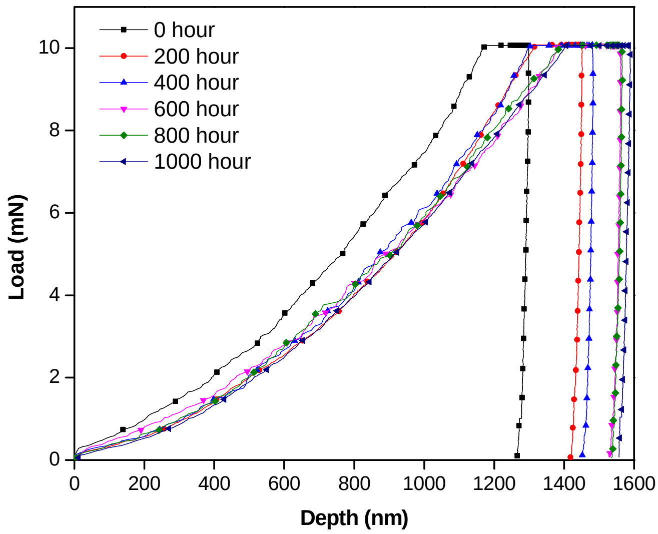


Fig. 2: Load versus depth for indentation of SAC305/ENIG subjected to HTS

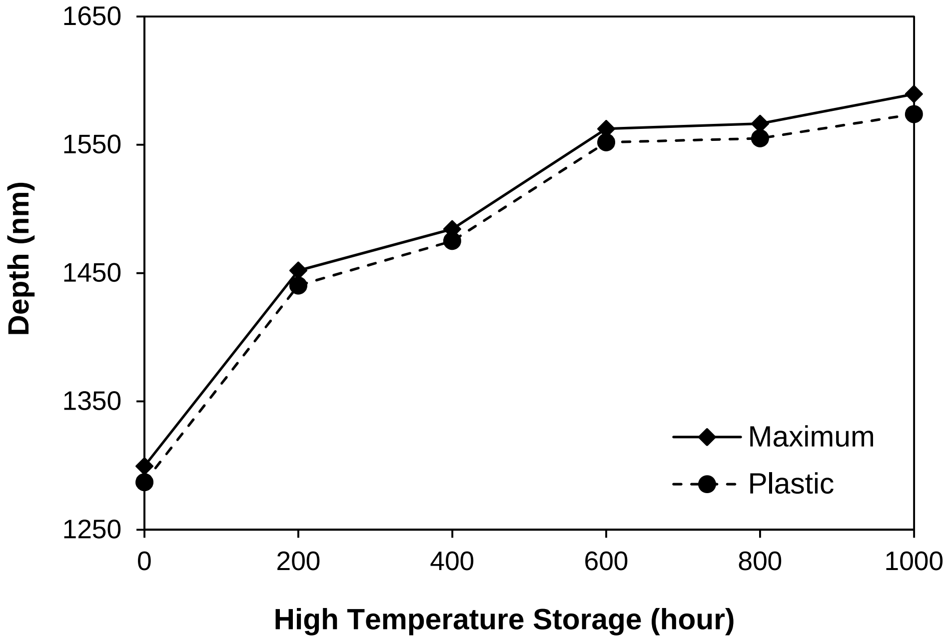


Fig. 3: Variation of maximum depth and plastic depth for SAC305/ENIG subjected to HTS

According to Fig. 5, the plastic work for 0 hour sample is 5.75 nJ has increased to 7.04 nJ for 600 hours and slowly increased to 7.06 nJ for 1000 hours. This represents that plasticity properties are increased with the HTS time. The elastic work is 0.19 nJ for non HTS sample has gradually increased to 0.21 nJ until 600 hours and increased up to 0.25 nJ as the HTS prolonged to 1000 hours. It is observed a clear trend of increasing plastic and elastic work. From this data, we can see that the plasticity-associated and elasticity-associated properties become stronger with the HTS time. This result has showing that the behaviour of the solder alloy exposed to HTS can be identify using nanoindentation test.

4. Conclusion

These findings suggest that in general the nanoindentation approach is able to provide variety of micromechanical properties data such as hardness, reduced modulus and plastic-elastic deformation occurences. Furthermore, this special tool has demonstrated the capability to analyse the localized micromechanical properties of SAC305 on ENIG surfaced finish subjected to the different high temperature storage (HTS) time. The results of this work show that the hardness of the SAC305/ENIG decreased with the increasing of HTS time while the reduce modulus is increase with HTS. It is observed that the plasticity-associated and elasticity-associated properties become stronger with the HTS time. The micromechanical data from nanoindentation test has provides more understanding on reliability of the solder joint.

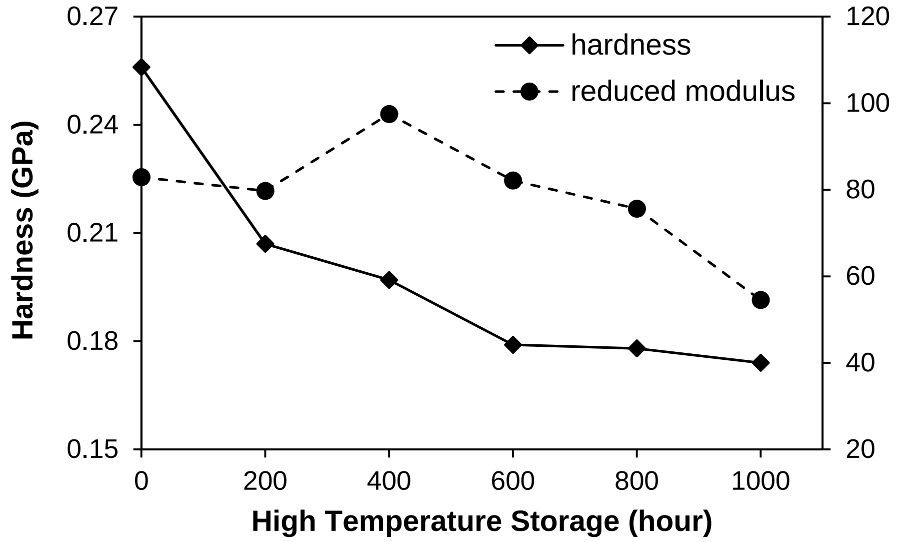


Fig. 4: Variation of hardness and reduced modulus for SAC305/ENIG subjected to HTS

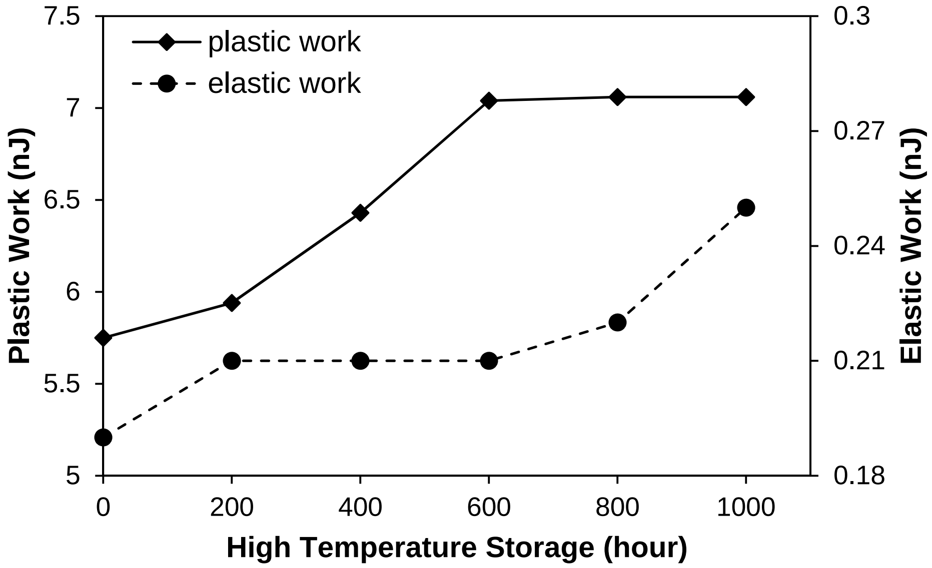


Fig. 5: Variation of plastic work and elastic work for SAC305/ENIG subjected to HTS

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