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Effect of Coating Element on Joining Stability of Sn-0.3Ag-0.7Cu Solder Joint due to Aging Test

(Kesan Unsur Salutan terhadap Kestabilan Sambungan Pateri Sn-0.3Ag-0.7Cu Akibat Ujian Penuaan Sesuhu)

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ABSTRACT

Solder joint is important for providing mechanical support and functionality of electronic packaging. Established solder joint should be able to withstand in device service operation and the environment without significant changes in terms of their microstructural evolution and mechanical properties. This study investigates the effect of the coating element (Sn and Ni) on the joining stability of Sn-0.3Ag-0.7Cu solder joint. The solder joints were exposed to different aging test for 1000 h to observed microstructure and micromechanical properties changes. Microstructural observation by means of intermetallic compound layer thickness due to the aging temperature effect. Joining stability by means of micromechanical changes were studied using nanoindentation approach. It was found that the elastic behavior, reduced modulus, and hardness of Sn-0.3Ag-0.7Cu solder joint has reduced due to aging test. However, the plastic behavior of Sn-0.3Ag-0.7Cu solder joint has increased with the increase of the aging temperature. It is observed that the Ni coating has a significant effect and a more stable solder joint achieved. This can be evidenced from small changes in intermetallic compound layer thickness and micromechanical properties were achieved using Ni coating as compared to Sn coating after subjected to the aging test for 1000 h.

Keywords: Aging; coating element; micromechanical properties; nanoindentation approach; solder joint stability

ABSTRAK

Sambungan pateri adalah penting untuk memberi sokongan mekanik dan kefungsian kepada pempakejan elektronik. Sambungan pateri yang baik seharusnya boleh bertahan ketika operasi penggunaan peranti dan persekitaran tanpa perubahan yang ketara dari segi perubahan mikrostruktur dan sifat mekanik. Kajian ini mengkaji kesan salutan dengan unsur (Sn dan Ni) terhadap kestabilan sambungan pateri Sn-0.3Ag-0.7Cu. Sambungan pateri tersebut telah didedahkan pada beberapa uji kaji penuaan yang berbeza selama 1000 jam dan perubahan mikrostuktur dan sifat mikromekanik diperhatikan. Pemerhatian mikrostruktur adalah dari segi perubahan ketebalan lapisan sebatian antara logam akibat uji kaji penuaan sesuhu. Kestabilan penyambungan dari segi perubahan mikromekanik telah dikaji dengan menggunakan pendekatan pelekukan nano. Kajian telah mendapati bahawa sifat elastik, penurunan modulus dan kekerasan sambungan pateri Sn-0.3Ag-0.7Cu berkurangan akibat daripada ujian penuaan. Walau bagaimanapun, sifat plastik bagi sambungan pateri Sn-0.3Ag-0.7Cu telah meningkat seiring dengan peningkatan suhu uji kaji penuaan sesuhu. Didapati bahawa salutan Ni menunjukkan kesan ketara yang mana sambungan pateri yang lebih stabil diperoleh. Kenyataan tersebut dapat dibuktikan dengan perubahan kecil ketebalan lapisan sebatian antara logam dan sifat mikromekanik dengan penggunaan salutan Ni berbanding dengan salutan Sn selepas didedahkan pada uji kaji penuaan selama 1000 jam.

Kata kunci: Kestabilan sambungan pateri; pendekatan pelekukan nano; penuaan sesuhu; sifat mikromekanik; unsur salutan

INTRODUCTION

Solder joint possesses electrical and mechanical bearing functions between electronic components and PCB pad in the microelectronic packaging field. Electronic packaging and assembly such as surface mount technology (SMT) adopted solder and soldering process between package lead and printed circuit board (PCB). The use of Sn-Pb solders was banned in electronic information products due to toxicity contamination and environmentally unfriendly. The RoHS directives have been issued to urge the use of lead-free solder such as Sn-Cu (Shang et al. 2019; Yao & Li 2020), Sn-Ag (Genanu et al. 2017; Kunwar et al. 2016) and Sn-Ag-Cu (SAC) (Fahim et al. 2018; Xiong & Zhang 2019; Xu et al. 2017) to replace Sn-Pb. The use of lead-free solders is required for products subjected to harsh environments in avionics, automotive and military applications.

The formation of Cu_6Sn_5 IMC layer during the assembly process of SAC with Cu substrate indicated the strong metallurgical bonding between the Cu surface-finished printed circuit board and electronic interconnections (Guo et al. 2018; Tang et al. 2016). However, the excessive growth of the brittle Cu6Sn5 phase will effect on reliability of the solder joints. Therefore, there is a need to use suitable coating materials of the PCB/Copper substrate. The coating located on the outermost layer of PCB either organic or metallic. Surface Mount Finish (SMT) is one of the methods to provide a planar mounting surface and urge the reliability of solder joints (Kim & Nishikawa 2017). The purpose of adding micro and nanocoating to SAC is to enhance the plastic deformation resistance of solders. This addition of reinforcing particles gives high stability of the mechanical properties of soldering whereby the solder wettability and temperature changes are negligible. Nevertheless, the researchers are attempted to use coating to form a bridge material since the coating materials act with lead free alloy to form IMCs during the soldering process. Wang et al. (2017) investigated Sn-58Bi coating on SAC305 at aging condition, the higher shear strength and through-solder ductile failure properties of IMC thickness layer. Xu et al. (2019) evaluated the Sn58Bi coating on SAC305 and were aged for 600 h at 80 °C. Micromechanical properties such as hardness of SnBi coating were reduced for pre and post aging conditions.

As it is well known, nanoindentation methods have recently become popular to determine micromechanical properties of soldering materials since the method is easy, rapid, and non-destructive technique to obtain the information of the mechanical properties especially the micro/nanoscale of materials (Ismail et al. 2020; Jalar et al. 2020). Previous solder joint nanoindentation studies of SAC were done at different temperature (Ahmed et al. 2017; Fahim et al. 2018; Hasnine et al. 2017), different coatings such as carbon-based nanomaterials graphene nanosheets (GNSs) (Khodabakhshi et al. 2017), carbon nanotubes Ag (Plevachuk et al. 2019), Ni (Huber et al. 2016), Al (Nor Ilyana 2017), nanoceramics (Yakymovych et al. 2017), and nanometals (Ani et al. 2018).

Most prior researcher is working on the solder mechanical properties and aging effects such as shear testing, tension, and compression of miniature lead free solder (Hasnine et al. 2017; Xu et al. 2019). Nevertheless, there is more limited number in literature that studied aging effects by micromechanical loading of Ni and Sn coating of SAC307 lead free soldering using stencil method. Our previous work suggested that the Ni coating can control the intermetallic growth exposed to the aging test (Abu Bakar et al. 2018). In this paper, the changes in micromechanical properties will be further analyzed on the effect of the coating element towards the solder joint stability. The main objective of this study was to investigate the effect of Sn and Ni coating the solder SAC 307 micromechanical properties micro solder joints at different isothermal aging temperature. Nanoindentation was used to evaluate the reduced modulus, hardness, elastic and plastic behaviors. Additionally, EDS and FESEM were used to observe the intermetallic layer compound the Sn and Ni coating SAC 307. The influence of Sn and Ni elements on the micromechanical properties of solder joint SAC 307 was discussed.

MATERIALS AND METHOD

A printed circuit board (PCB) with Cu metallization layer has been coated with (a) Sn layer and (b) Ni layer. These coated PCB/Cu was then soldered with a lead-free solder paste of 99%Sn-0.3%Ag-0.7%Cu (SAC 0307). Solder particle used in the solder paste is type 4 with a diameter range of approximately ~30 mm. The solder paste was printed into the coated PCB using the stencil. The printed PCB was then reflowed using a reflow oven (Madell Technology Corporation) at 235 °C. The as-reflow samples were then subjected to aging with temperature of 60, 90, 120, and 150 °C for 1000 h. This is similar to high temperature storage testing which is normally been used in reliability testing of electronic packaging as suggested by JEDEC (2009). The aging activities were carried out to induce the growth of IMC, due to the diffusion process. Then, the samples were cross-section following standard metallography with consideration given for soft materials. The microstructural observation was carried out using field emission scanning electron microscope (FESEM) equipped with an energy dispersive spectrum (EDS) and optical microscope with image analysis capability. The IMC growth indicated by the increment of IMC thickness has been analyzed through considering stereometry and statistical analysis which 300 points of IMC thicknesses were taken (Bakar et al. 2018). The micromechanical properties have been studied via nanoindenter (Micro Materials Nanotest™) with diamond Berkovich indenter. The indentation was made onto the solder area with a constant rate of 0.5 mN/s for both loading and unloading. The load was applied to the sample surface until reached maximum load of 10 mN, followed by dwell time for 30 s before unloading process.

RESULTS AND DISCUSSION

Figure 1 shows the FESEM Micrograph of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with Sn and Ni coating after aging at 150 °C for 1000 h. It is seen that the intermetallic compound (IMC) layer on PCB/Cu with Sn coating is thicker compared to the Ni coating. This is due to Ni layer that existed on the interface between the solder and Cu substrate. The EDS result in Figure 2 showing the presence of Sn and Cu elements for intermetallic growth for the solder joints. The presence of thin Ni coating is confirmed in Figure 2(b).

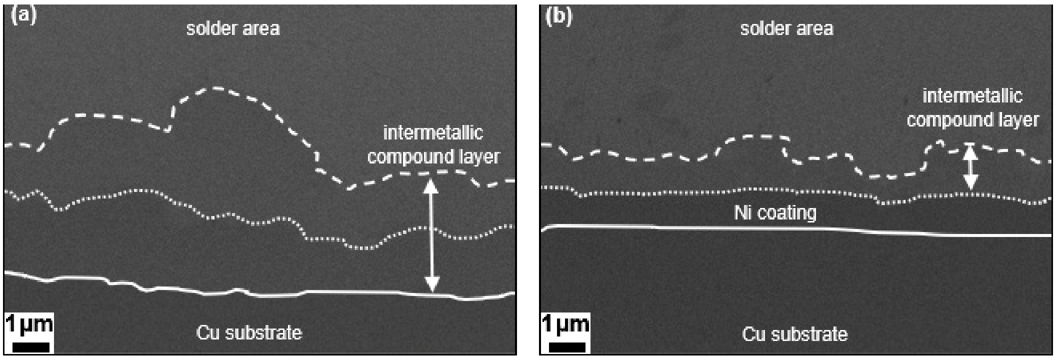
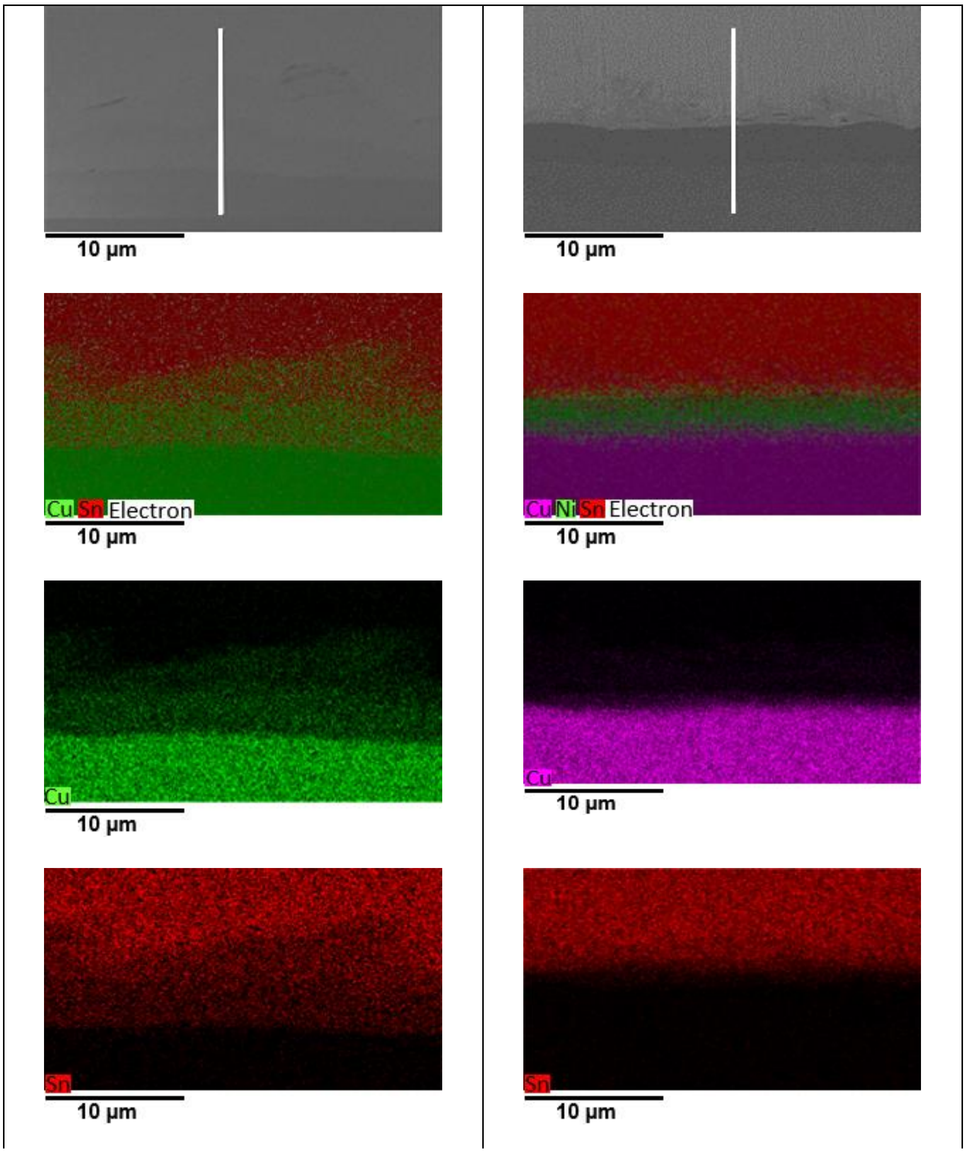


FIGURE 1. FESEM Micrograph of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with: (a) Sn, and (b) Ni coating after aging at 150 °C for 1000 h



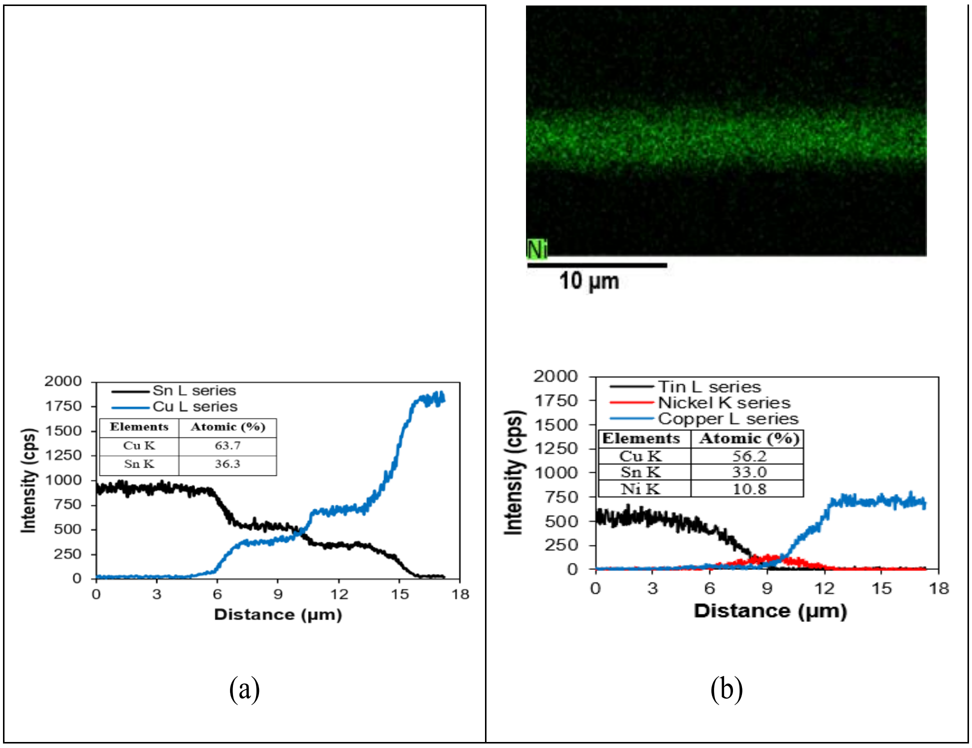


FIGURE 2. EDS analysis of interfacial intermetallic layer of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with: (a) Sn, and (b) Ni coating subjected to aging for 1000 h

IMC layer thickness results are shown in Figure 3. Intermetallic compound (IMC) of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with Ni and Sn coatings has increased progressively with aging temperature. The thickness of IMC for the solder joint on Sn coating is 3.3 µm for the controlled sample has increased up to 8.3 µm after aging at 150 °C. IMC on Ni coating has shown smaller changes from 2.0 µm for a controlled sample and increase to 5.7 µm after aging at 150 °C. The increment of IMC layer thickness is 3.7 and 5.0 µm for Ni and Sn coating respectively due to aging temperature of 1000 h. Our previous work also has reported on the activation energy for intermetallic growth (Bakar et al. 2018). Higher activation energy is obtained for Ni coating, 41 kJ/mol compared to Sn coating, 39 kJ/mol. This result demonstrated that the coating elements have a profound effect on the IMC growth. This in agreement with observation by Anuar et al. (2020), the IMC thickness of electroless Ni coating/SAC405 after the aging time (1000 h) at range of 4.45 µm which is higher form our findings. Nevertheless, the thinner IMC thickness could represent good micromechanical properties and better metallurgical bonding of soldering (Ramli et al. 2019).

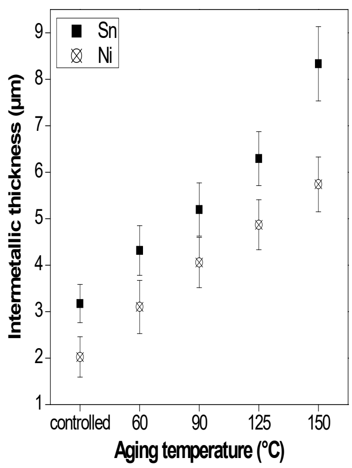


FIGURE 3. Intermetallic thickness of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with different coating subjected to aging for 1000 h

Figure 4 shows the load versus penetration depth curves of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with different coating subjected to aging at 150 °C for 1000 h. The load displacement curve profile presented a solder joint behavior from the elastic region to the plastic region. Penetration depth results during the loading process are shown in Figure 5. It is observed that the maximum and plastic depth were increased with the increase of the aging temperature. Maximum depth for the solder joint on Ni coating shows small changes from 1382 to 1495 nm after aging at 150 °C as compared to Sn coating from 1274 to 1510 nm. The value of plastic depth is 1261 to 1498 nm for Sn coating after the aging temperature at 150 for 1000 h. While for Ni coating, the value of plastic depth is 365 nm to 1489 nm after aging temperature at 150 for 1000 h. The increase of plastic depth changes by 19% Sn coating and 9% Ni coating were found for plastic depth changes.

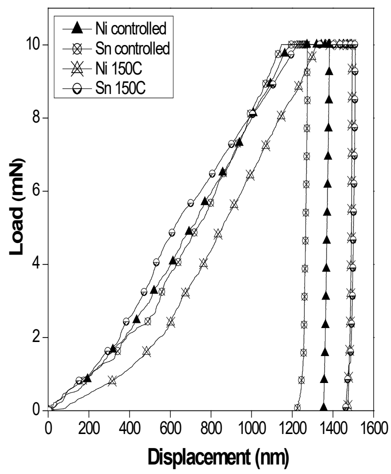


FIGURE 4. Load displacement curve of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with different coating subjected to aging at 150°C for 1000 h

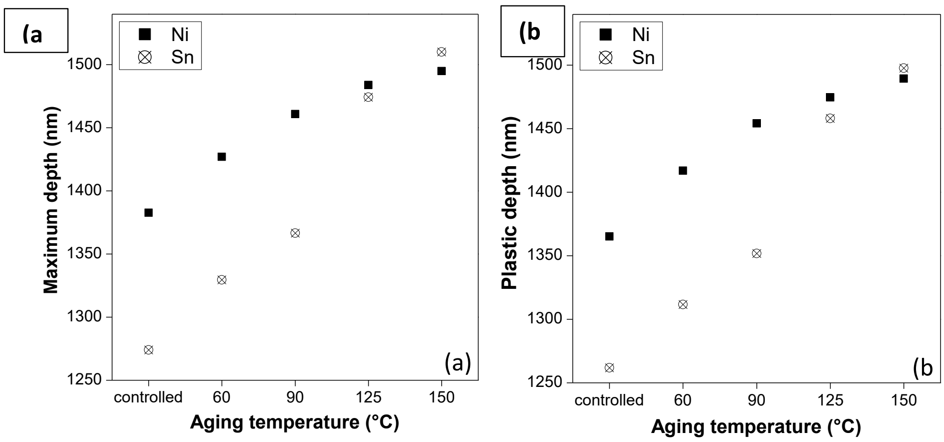


FIGURE 5. (a) Maximum, and (b) plastic depth properties of Sn-0.3Ag-0.7Cu solder joint on PCB with different coating subjected to aging for 1000 h

Figure 6 shows that the hardness and reduced modulus of the solder joint after exposed to different aging for 1000 h. The hardness of the solder joint on PCB/Cu with Sn coating is 246 MPa for a controlled sample and noticeably reduced to 177 MPa after exposed to aging at 150 °C. While fewer changes on the hardness for solder joint on PCB/Cu with Ni coating, 211 MPa to 179 MPa approximately 16% reduction as compared 28% for Sn coating. Reduce modulus result for solder joint on PCB/Cu with Sn coating from 133 decreased to 54 GPa after aging at 150 °C. Similar observation but fewer changes are observed for solder joint on PCB/Cu with Ni coating from 151 to 88 GPa, approximately 42% as compared to Sn coating, 59% reduction from controlled sample. The findings show that the hardness and reduced modulus are decreased with the increase of the aging temperature. These observations suggest there are softening effects on the solder joint strength after the aging test. This finding agrees with plastic work which increased from 5.73 to 8.48 nJ for Sn coating and 6.32 to 7.31 nJ for Ni coating after aging at 150 °C (Figure 7). Meanwhile, the elastic work has decreased from 0.19 to 0.11 nJ for Sn coating and 0.13 to 0.08 nJ for Ni coating after aging at 150 °C (Figure 7). The decrease of elastic properties of Sn and Ni coating by 42 and 38%, whereas the increase of plastic work by 48 and 16% of Sn and Ni coating.

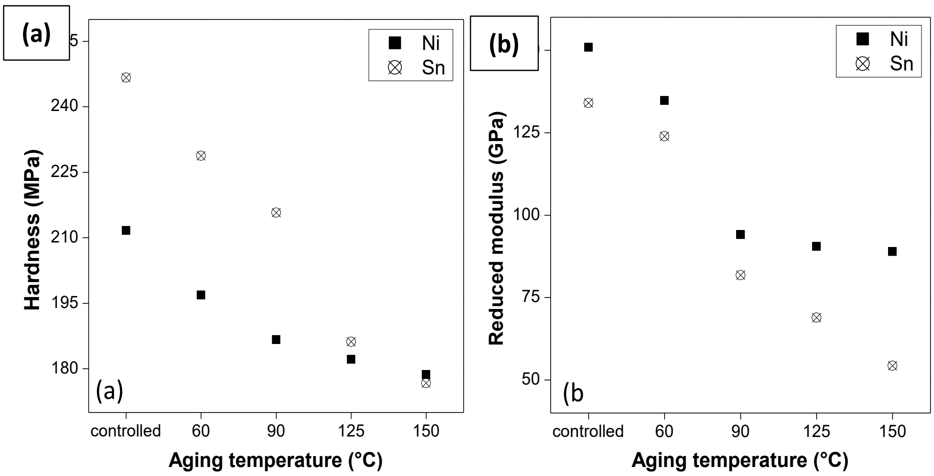


FIGURE 6. (a) Hardness, and (b) reduced modulus properties of Sn-0.3Ag-0.7Cu solder joint on PCB with different coating subjected to aging for 1000 h

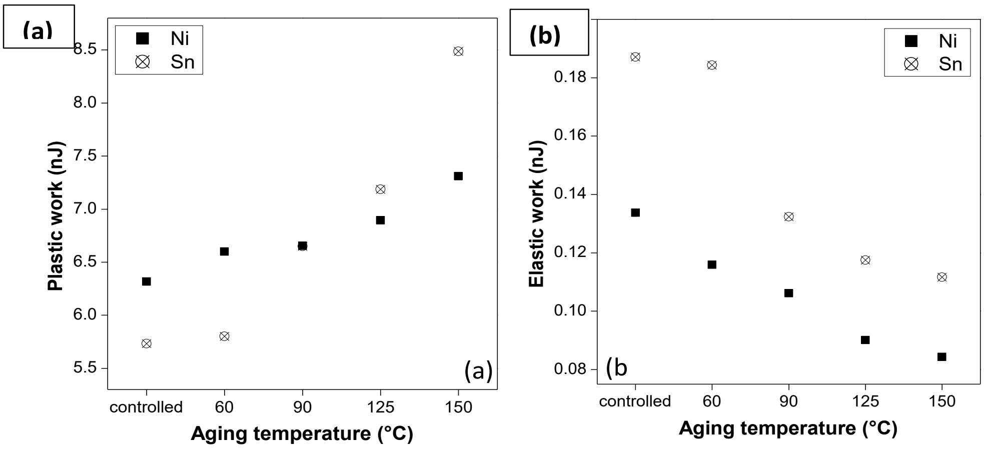


FIGURE 7. (a) Plastic, and (b) elastic work properties of Sn-0.3Ag-0.7Cu solder joint on PCB with different coating subjected to aging for 1000 h

Conclusion

The nanoindentation approach has successfully discovered the joining stability of Sn-0.3Ag-0.7Cu solder joint on PCB/Cu with different coating subjected to aging for 1000 h. It was found that the solder joint on Ni coated PCB/Cu is more stable as compared to Sn coating after subjected to aging at 1000 h. Solder joint on Ni coated PCB/Cu shown smaller microstructural changes in terms of intermetallic compound layer thickness by 3.7 µm due to aging temperature for 1000 h. Smaller micromechanical changes of Ni coated PCB/Cu by 16 % for hardness, 42% reduce modulus, 38% elastic and 16% plastic work as compared to Sn coating.

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