Micromechanical Properties of Solder Joint Towards Air Blast Exposure

W.Y.W Yusoff1,a*, N.S. Safee1,b, A. Ismail1,c, M.A. Bakar2,d and A. Jalar2&3,e

1Center for Defence Foundation Studies, Universiti Pertahanan Nasional Malaysia, Kem Sg. Besi, 57000 Kuala Lumpur, Malaysia.
2Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
3School of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.

a*yusmawati@upnm.edu.my,bnshafiqasafee@gmail.com,cariffin@upnm.edu.my, dmaria@ukm.edu.my, eazmn@ukm.edu.my

Abstract. In modern war fighting and conflict prevention, the important of electronics has been and continues to be the fastest moving in technology areas. The key process in industrial manufacture of electronic device is soldering. Sn-Ag-Cu solder have been recommended to replace Sn-Pb solder in the chip-joint process because of low cost and large volume consumer product. In order to study the micromechanical properties of SAC 0307, the blast test was conducted using 500 g and 1000 g of trinitrotoluene (TNT) and the samples were fixed to two meter distance. The effect of micromechanical properties of SAC 0307 were investigated using nanoindentation technique. The hardness and reduced modulus of SAC 0307 were decreased while the plastic work increased when the source of blast increased. The characterization especially after air blast exposure in order to accurately predict the reliability of solder joints there were very large discrepancies in both the tensile and creep properties provided in Sn-Ag-Cu current databases.

1. Introduction
In modern electronics packaging, the system interacts with users, other systems, the platform on which it operates, the signal or data acquisition, dispensing, processing and actuation functions while performing that electronics makes possible. These functions support communications, weapons delivery, electronic warfare, surveillance, platform control, logistics, associated with modern military forces and their missions. In order to protect environment, the adoption of lead free solder has become unavoidable trend among researcher. However, the properties of lead-free solders are stiffer, brittle, feeble to dynamic loads rather than solders containing lead, which are frequently applied in portable electronic devices during normal or extreme conditions [1]. Therefore, any lead-free solder alternative for military application must conform to this broad range of properties and characteristics to be accepted as suitable and reliable candidate to replace the eutectic Sn-Pb solder. Specifically, solder joints of high-density, high-performance electronic packages are expected to withstand increasing mechanical, electrical, and thermal loads, which can cause serious reliability issues and cases of failures during manufacturing or while in operation [2]. Lee & Mohamad [3] reported that Sn-Ag-Cu...
alloys is the most promising lead-free solder candidates due to their relatively low melting temperature, superior mechanical properties, and good compatibility with other components. Most studies of SAC solder alloys cover reliability, solderability, intermetallic compound (IMC) evaluation by shear strength behaviour, tensile and wettability properties or electromigration behaviour as well as at high current density and high temperature [4].

Nanoindentation has received an attention for measuring the hardness and Young’s modulus of bulk materials and thin films microstructural phases also as valuable technique for penetrating the mechanical behavior of materials at narrow areas. According to Deng et al. [5], analysis of nanoindentation includes internal friction and damping properties such as activation energy, stress exponent for creep, the storage and loss modulus, and fracture toughness of brittle materials.

However, the study on micromechanical properties of solder alloy towards blast wave was not fully discover yet. In this research, trinitrotoluene (TNT) was used as the source of exposure. The explosive charge was detonated in the air, the blast waves propagated spherically outwards impinged directly onto the sample without prior interaction with other obstacles or the ground. The objective of this work is to investigate the micromechanical properties of SAC solder towards blast exposure using nanoindentation technique.

2. Materials and Methods

2.1 Sample Preparation
Lead free solder paste, SAC 0307 consist of Sn 99%, Ag 0.3% and Cu 0.7% was supplied by Redring Solder (M) Sdn. Bhd. Firstly, the SAC 0307 solder paste was deposited on the printed circuit board (PCB) using a stencil and undergo reflow soldering process at 215°C for 8 seconds. Then, the samples were exposed to TNT equivalent with 500 g and 1000 g and were placed at two meter distance from the blast sources and non-exposure sample was used as control. Prior the blast test, the SAC 0307 sample were covered with satin. After the exposure, the test board were cut approximately 0.5 cm × 0.4 cm × 0.2 cm dimension undergo cross-sectioned for cross-sectioned for standard metallographic technique such as (1) mounting using mixed of hardening resin powder and epoxy resin liquid, (2) grinding with silicon carbide abrasive paper from 400 until 1200 grits and (3) polished with DP Nap polishing cloth, liquid lubricant and 1μm of diamond spray to prepare the cross-section for nanoindentation test [6].

2.2 Nanoindentation Test
Nanoindentation test was carried out at room temperature using nanoindenter machine (Micro Materials, NanoTestTM) with Berkovich tip as shown in figure 1. The indentation test was performed at the middle of solder cross section. A constant of loading and unloading rate of 0.5 mN/s was applied to the sample surface until reached at 10 mN (maximum load). The dwell time was 30 seconds at maximum load followed by the unloading process [7]. The graph from this experiment shows the hysteresis of load versus depth. This hysteresis consists of three segments, which were loading, dwell time at target load, and the unloading processes. The loading curve is a function of loading rate or strain rate. The unloading curve is tightly related to elastic recovery which used power-law model to the examination of reduced modulus. The dwell time at target load was used to investigate the creep deformation at a certain temperature.
3. Results and Discussion

During indentation process, the load \( (P) \) and depth \( (h) \) was recorded concurrently. The \( P-h \) curves of SAC 0307 solder with different blast source are plotted as shown in figure 2. This \( P-h \) curve reflects the mechanical behaviour of solder [8]. From this figure, the SAC 0307 solder with 1000 g blast source displayed the presence more pop-in (indicates by arrow) as compared to control and 500 g blast source. The pop-in event indicates the local discontinuity during loading process. The shift from elastic to plastic deformation of the SAC 0307 solder can be observed at the very earliest stages (initial pop-in event) of the mechanical contact known as ‘incipient plasticity’. The following pop-ins related to the microstructure of materials [9].

![Figure 1. Nanoindenter machine](image1)

**Figure 1.** Nanoindenter machine

![Figure 2. P-h profile of SAC 0307 solder on PCB with different blast source](image2)

**Figure 2.** \( P-h \) profile of SAC 0307 solder on PCB with different blast source

Figure 3 shows the relationship between hardness and plastic work of solder joint on PCB with different weight of blast source (control, 500 g and 1000 g). It is observed that the hardness of SAC 0307 decrease while the plastic work increased when the weight of blast source increased. The migration of interstitial atoms and lattice vacancies along the gradient of a grain boundary cause deformation when presence of tension or compression pressure in reversed directions. These lattice defects tend to move in whichever direction will relieve the imbalance of pressure, and cause creep deformation due to under pressure [10]. The brittleness of a material may be gain from the value of hardness. With an increase in the weight of blast source, the hardness was decreased. This hardness is in line with the result from the indentation depth indicates that the solder material is becoming soft after exposure to blast source. Softening behavior in the metal usually occur due to changes in the
microstructure. However, the accurate measure of hardness should be avoid fracture events that may lead to an indentation size effect in order to estimate a yield stress [11].

![Graph showing relationship between hardness and plastic work of SAC0307 with different blast source.](image1)

**Figure 3.** Relationship of Hardness and Plastic Work of SAC0307 with different blast source

The reduced modulus and elastic work relationship is shown in figure 4. The reduced modulus (atomic binding) of samples decreased when the weight of blast source increased. The elastic work for before blast and after 500 g decreased but when the blast source increased to 1000 g the elastic work increased. Cheng et al. [12] stated that the elastic work of Sn-0.3Ag-0.7Cu (SAC 0307) shows higher bulk compliance and higher plastic energy dissipation compare to SAC 405 or SAC 305. Regardless, the consequent of a lower Ag content will rising the primary b-Sn phase (large b-Sn grains) and degradation of thermal mechanical fatigue. Thus, Sn-0.3Ag-0.7Cu solder have lower tensile strength and elastic modulus compare to higher of Ag content solder [13]. Exposure to blast resulted microstructure change as shown in the micromechanical result using nanoindentation test.

![Graph showing relationship between reduced modulus and elastic work of SAC0307 with different blast source.](image2)

**Figure 4.** Relationship of Reduced Modulus and Elastic Work of SAC 0307 with different blast source
4. Conclusion
The micromechanical properties of SAC 0307 solder on printed circuit board with different blast source has successfully investigated using nanoindentation technique. The hardness and reduced modulus values decreased with the increment of blast source, while the plastic and elastic work increased after exposure to high blast source. As subjected to blast, the solder become softer. Blast exposure resulted the changes in the microstructure of the solder materials.

Acknowledgement
The authors are gratefully acknowledged the financial support from FRGS/1/2015/SG06/UPNM/03/1, Universiti Kebangsaan Malaysia (UKM) and Redring Solder (M) Sdn. Bhd. for research materials and collaboration work.

References
[1] Y. Lai, P. Yang, C. Yeh, Experimental studies of board-level reliability of chip-scale packages subjected to JEDEC drop test condition, Microelectron. Reliab. 46 (2006) 645–650.
[2] A. Fortier, M. G. Pecht, A perspective of the IPC report on lead-free electronics in military/aerospace applications, Microelectron. Reliab. 69 (2017) 66-70.
[3] L. M. Lee, A. A. Mohamad, Interfacial reaction of Sn-Ag-Cu lead-free solder alloy on Cu: A review, Advances in Mater. Sci. Eng. (2013), ID123697, 11 pages.
[4] B. Medgyes, D. Rigler, B. Illés, G. Harsányi, L. Gál, Investigating of Electrochemical Migration on Low- Ag Lead-Free Solder Alloys, 18th International Symposium for Design and Technology of Electronic Packaging (2012) 147-150.
[5] X. Deng, N. Chawla, K.K. Chawla, M. Koopman, Deformation behavior of (Cu, Ag)-Sn intermetallics by nanoindentation, Acta Materialia, 52(14) (2004) 4291-4303.
[6] M. A. Bakar, A. Jalar, A. R. Daud, R. Ismail, N. A. C. Lah, N. S Ibrahim, Nanoindentation approach on investigating micromechanical properties of joining from green solder materials, Sains Malaysiana45(8) (2016) 1275–1279.
[7] M. A. Bakar, A. Jalar, R. Ismail, A. R. Daud, Nanoindentation of Sn3.0Ag0.5Cu/ENIG Solder Joint after High Temperature Storage, Materials Science Forum 857(3)(2016) 40–43.
[8] C. A. Schuh, Nanoindentation Studies of Material, Materials Today 9(5)(2006) 32-40.
[9] B. Yang, H. Vehoff, Grain size effect on the mechanical properties of Nanonickel examined by nanoindentation, Mat. Sci. Eng. A-Struct 400-401(2005) 467-470.
[10] H.Ma, J. C. Suhling, A review of mechanical properties of lead-free solders for electronic packaging, J. Mater. Sci. 44 (2009)1141–1158.
[11] R.R.Chromik, R. P.Vinci, S. L. Allen, M. R Notis, Measuring the Mechanical Properties of Pb-Free Solder and Sn-Based Intermetallics by Nanoindentation. JOM 6 (2003) 66-69.
[12] F. Cheng, F. Gao, J. Zhang, W. Jin, X. Xiao, Tensile properties and wettability of SAC0307 and SAC105 low Ag lead-free solder alloys. J. Mater. Sci.46(2011) 3424–3429.
[13] Y. Tang, S. M. Luo, W. F. Huang, Y. C. Pan, G. Y. Li, Effects of Mn nanoparticles on tensile properties of low-Ag Sn-0.3Ag-0.7Cu-xMn solder alloys and joints. J. Alloy. Compd. 719(2017) 365–375.