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Thermal Aging Impact on 95.5%Sn-3.8%Ag-0.7%Cu (SAC387) and Tin-lead (SnPb) Properties

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Abstract: Lead (Pb) is poisonous by nature, it was ban by the protection agencies. It cause to increase the research on lead free solder materials. In this research SAC387 soldering material was selected to investigate the microstructure changes and mechanical properties at different thermal conditions. Optical microscope and scanning electron microscope were used to measure the grain size, intermetallic compounds (IMCs) and elemental composition of material. Tensile properties was measured at room temperature conditions by using universal testing machine (UTM). We studied that microstructure changes and strength of material is totally dependent on the thermal aging temperature and time. By increasing the temperature, the strength of material is decrease. Strength of lead-free soldering material is inverse proportions to thermal temperature and time. This project report is concerned with composition analysis, microstructure and mechanical properties of SAC387.

Keywords: SAC387, microstructure, IMCs, tensile properties, lead-free solder.

I. INTRODUCTION

Use of solders in electronic devices/boards is very old technique. The reason behind the used of lead solder alloy in electronic is rational properties of alloy. The properties are good melting points, wettability, excellent corrosion resistance, low cost, conductivity and mechanical properties[1]. Lead compound is banned by environmental protection agency (EPA) due to hazardous to humans and environment. As, the disposal of lead compounds proper land fill or to be store in the safe plac. Use of Pb alloy material was introduced in senate and the house of representatives in the united states (US). The legislation includes H.R. 2922; the lead based paint hazard abatement act of 1991, S. 391; the Lead Exposure Reduction Act of 1991, and H.R. 3554; the lead exposure act of 1992 [2]. The use of some halogenated flame retardants like lead, mercury and cadmium used to be limited and be phase out [3]. For electronics manufacturers to attain lead recycling 100% percent or to use lead free solders. The alternative lead-free solder alloy have the equivalent melting point, good wettability, availability and cost to Pb based solder alloys.

Commercial and experimental soldering material exists but none can meet all the above requirements. They also require possessing the desirable material properties and the industry is prepared to meet the increase in processing temperature. Japanese companies had been forced to manufacture lead-free soldering alloy material [4]. The international association scrutinized the availability of existing lead-free alloys for electronics. Japanese government suggested to adopted tin–3.0wt.% silver–0.5wt.% copper (Sn–3.0Ag–0.5Cu) alloy and American electronics manufacturing initiative (NEMI) adopt Sn–3.9Ag–0.6Cu alloy. The proposed alloys need improvements to replace the existing alloys. It is recommended that proper elemental composition lead-fre solder alloys are essential [5]. According to current requirement soldering material should be reliable and good electrical and mechanical properties. For the lead-free solders, Sn-Bi, sliver (Ag), copper (Cu), indium (In), zinc (Zn) and antimony (Sb) are considered as the main alloy contents. The binary alloy does not meet with the requirements so some other elements have been included for the improvements which are called ternary and quaternary lead free solders [6–8]. Thermodynamics calculation for lead free solders has been included for material and micro alloy evolution [9-11]. For the electronic devices are thin and small. The solder joint on the thin boards will automatically small. The research is going on, to improve strength and particles reinforcing which can hold grain growth, grain-boundary sliding and IMCs formation. Furthermore, research on stress uniformity is also under consideration. Besides this, for suitable physical properties, the composites and IMCs from nikle, copper, silver, Ag3Sn Cu5Sn5 of solder alloy mainly aimed [12–15].

Silver (Ag) and copper (Cu) percentage change altered the properties of alloy. They are used for the development of materials used in superconductors, hydrogen storage, ceramics and glasses [16].

In this paper, the recent developments in lead-free solder alloys and the effect on microstructure, tensile properties, creep behavior and wetting performance. The refinement of the microstructure and behavior of these alloys in the form of solder joints to indicate their potential of meeting the reliability requirements.

II. EXPERIMENTAL PROCEDURE

Composition analysis were carry out for SAC387 soldering materials by using SEM and energy dispersive spectroscopy (EDS/EDX). Then thermal aging of lead-free soldering material SAC387, were performed at 50 °C, 100 °C and 150 °C for hundred hours. Each specimen was polished and etched for optical microscope and scanning electron microscope. Etching was carried out for optical microscope for 30 seconds with an etchant solution of 5 % HCL and 95 % ethanol, to measure the microstructure change and grain size. Strength of material were measured at room temperature, 50 °C, 100 °C and 150 °C. The obtained results were further processed, to compare the properties of SAC387 with lead containing material. Figure 1 shows the complete procedure followed for the present study.

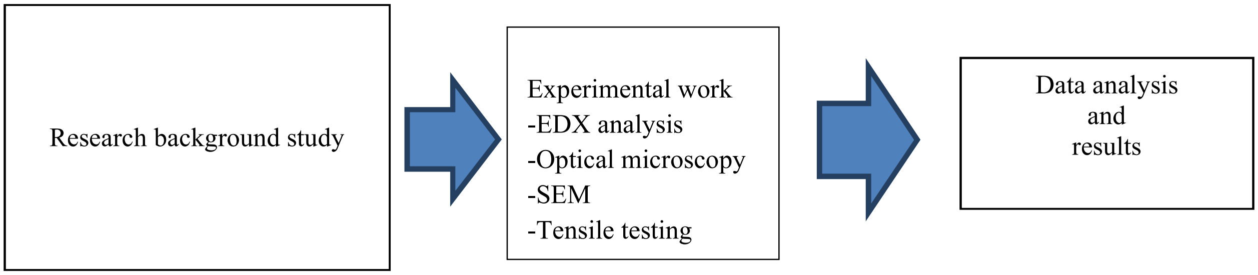


Fig 1. Experimental procedure.

III. RESULTS AND DISCUSSION

SAC387 soldering material was analyzed in normal conditions for compositional details of material. Figure 2 show SEM images of SAC387. Material main contents are tin (Sn), silver (Ag) and copper (Cu). The elemental details of SAC387 material have been discussed in section 3.1. EDX/EDS analysis. In figure 3 show the optical microscope images for four specimens. Specimens were thermal aged at different temperatures for 100 hours. The details of specimen are (a) specimen 1– room temperature (23 ^{O}C) (b) specimen 2– 50 ^{O}C (c) specimen 1– 100 ^{O}C (d) specimen 1– 150 ^{O}C. Figure 4-6 illustrate the microstructure and solder joint inter-metallic compound details of SAC387 soldering alloy. Figure 7 show the stress and strain graph of SAC387 and SnPb.

A. EDX/EDS Analysis

Elemental analysis of SAC387 were performed by using SEM. SEM image and EDX analysis image were shown in figure 2. The results of composition analysis show that the effective contents of material contain Sn 95.35 percent by weight, Ag 3.71 percent and Cu 0.67 by weight percent. The compositional details of alloy are given in table 1.

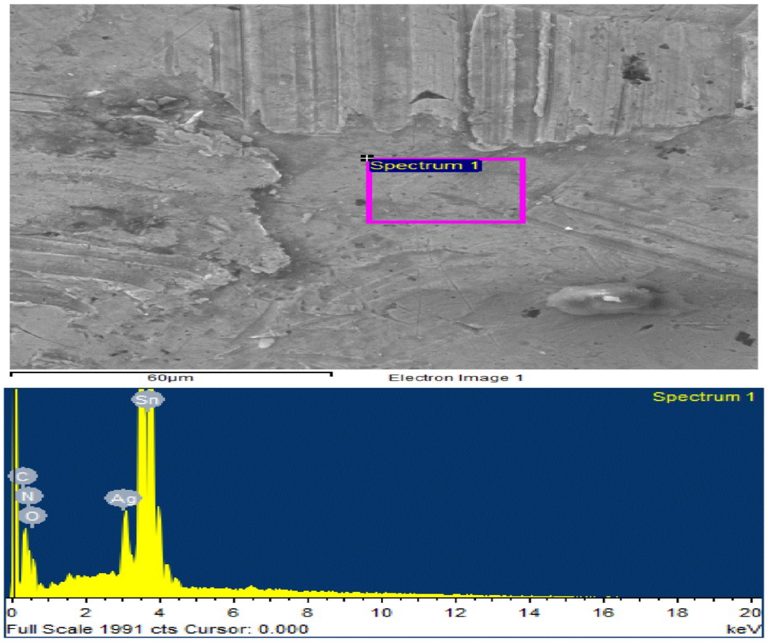


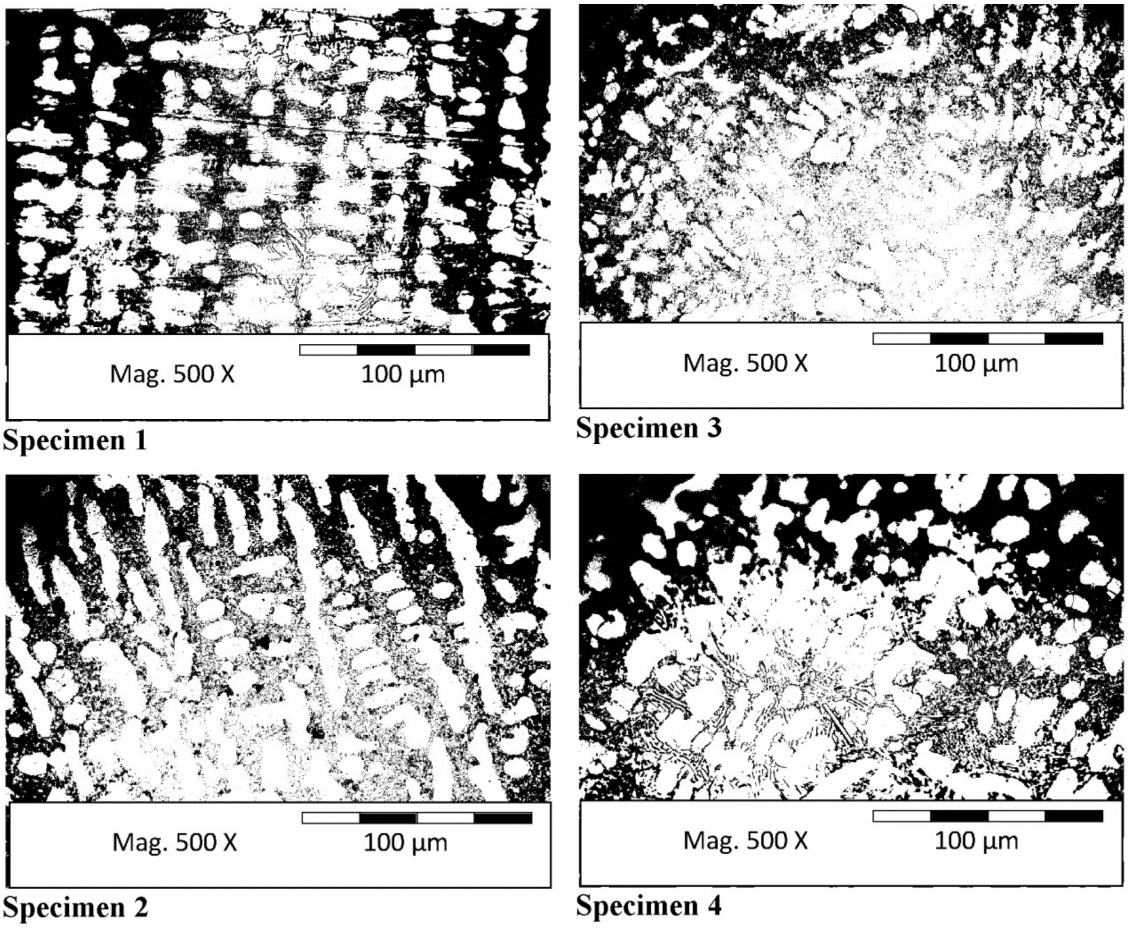
Fig 2. Elemental analysis of SAC387.

Table I
Elemental Composition of Lead-free Solder Alloy (SAC387)

Spectrum processing : Peaks possibly omitted : 1.740, 6.410 keV Processing option : All elements analyzed (Normalised) Number of iterations = 3	
Element	Weight%
C K	0.67
N K	0.13
O K	0.13
Ag	3.71
Sn	95.35
Totals	100.00

B. *Optical Microscopic Analysis*

Optical images of specimen 1, specimen 2, specimen 3 and specimen 4 of SAC387 are shown in figure 3. The grain size change results the change in strength and hardness properties of material. The thermal aging effect on grain size of samples were analyzed by using optical microscope. We observed that the grain sizes of samples were too much effected by thermal aging. So, SAC387 can resist high temperature, the solder joint of the material long life in high temperature zone.



Specimen 1

Specimen 3

Specimen 2

Specimen 4

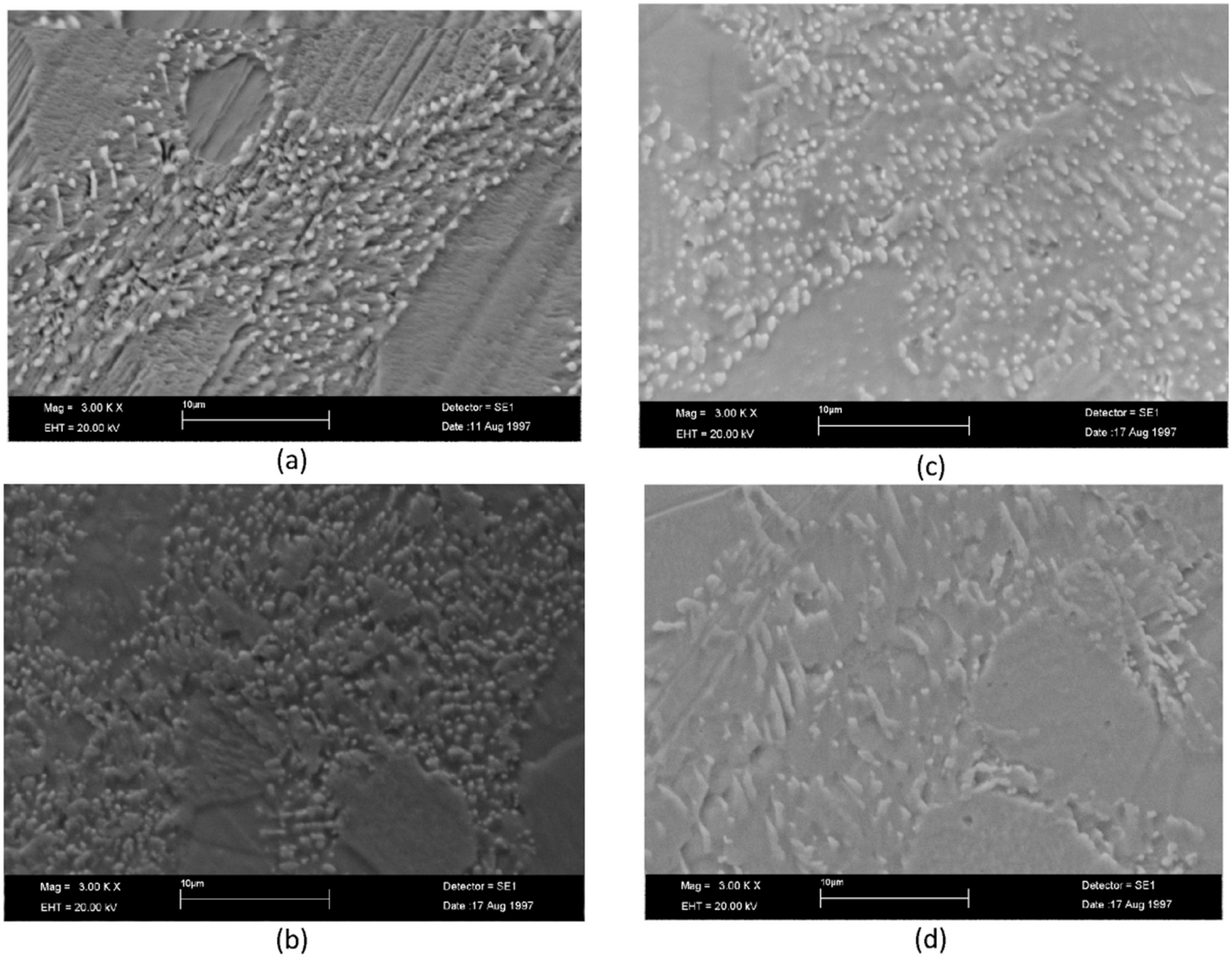
Fig 3. Optical microscope depictions of SAC387.

C. SAC387 Alloy Microstructure

Thermal aging temperature and time are the two parameters which impact on microstructure of SAC387. It cause the change in grain size and formation of IMCs. Three samples at 50 ^{O}C , 100 ^{O}C and 150 ^{O}C were keep in the furnace hundred hours. IMCs structural changes were examined in the microstructure examination. In sample 1 examination, we observed that it has coarse surface while in sample 2 examination, the surface was little rough. Correspondingly in sample 3, the surface examined was fine and in sample 4 the surface was finer and smoother. Sample 1-4 examined surfaces are depicted in figure 4.

Solder joint reliability, fracture, life and strength depend upon the growth of IMCs. The IMCs growth size has harmful impact on joint properties. In this study the growth of IMCs were examined by keeping the solder on copper at high temperature. The thermal temperature and time were not in controlled in this case and the formation of IMCs layers effect the kinetics growth in long thermal aging. More ever, the IMCs layers growth will deteriorate strength of joint and reliability, due to brittle character [17-20]. Copper-tine intermetallic identified same as Cu_6Sn_5 layer by X-rays spectroscopy and silver-tin IMCS as Ag_3Sn in solder matrix. Tin-silver (Sn-Ag), tin-silver–0.25silver and tin-silver–0.5RE structure were identified. It was observed that the structure are similar to intermetallic layer (IML) thickness. With increase the thermal aging time IMLs thickness increases.

For IMCs details of solder joints SnPb and SAC387, XRD analysis were carried out. All samples (SnPb and SAC387) were aged for 100hrs, 200hrs and 300hrs. IMCs layers thickness was measured and shown in figure 5 and figure 6. From figure 5-6 results, it is concluded that the tin-lead IMCs thickness are more than SAC387 for every thermal aging period and the thickness of Cu6Sn5 was more than Cu3Sn. The final conclusion was IMCs thickness is dependent on aging time and temperature. The IMCs thickness and aging time are directly proportional to each other.



(a) (c)

(b) (d)

Fig 4. Microstructure of SAC387 annealed for 100 hours at: (a) sample 1– 23 ^{O}C (b) sample 2– 50 ^{O}C (c) sample 1– 100 ^{O}C (d) sample 1– 150 ^{O}C.

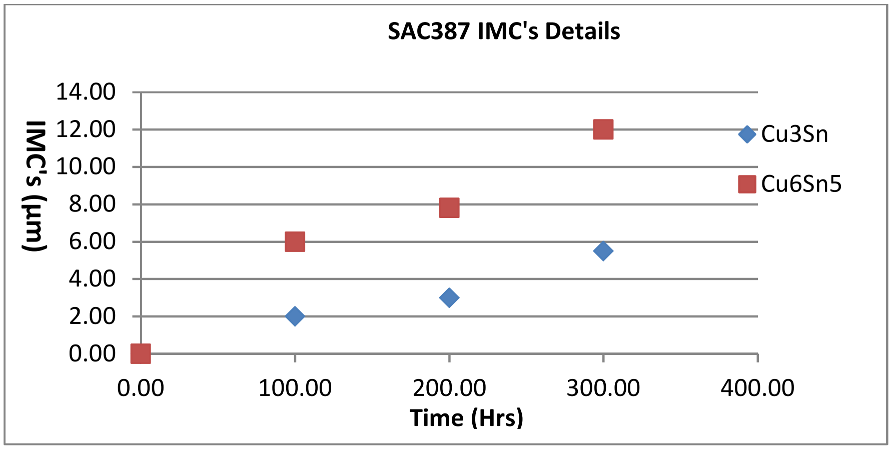


Fig 5. Solder joint IMCs thickness details of SAC387.

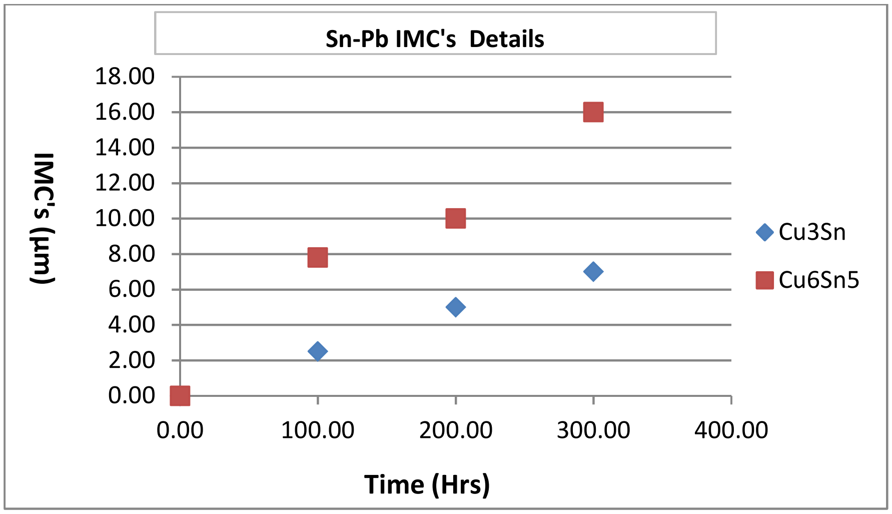


Fig 6. Solder joint IMCs thickness details of Sn-Pb.

D. Strength Analysis of Soldering Materials

Tensile tests were performed for lead-free soldering material (SAC387) and lead soldering material (SnPb).We observed that SAC387 can bear more stresses than SnPb which is depicted in figure 7. SnPb deform more than SAC387 for the same stress value. The properties of SAC387 is much better than SnPb. The Tensile test specimen dimensions details, elongation, stress and stain energy for both tensile test are shown in table 2.

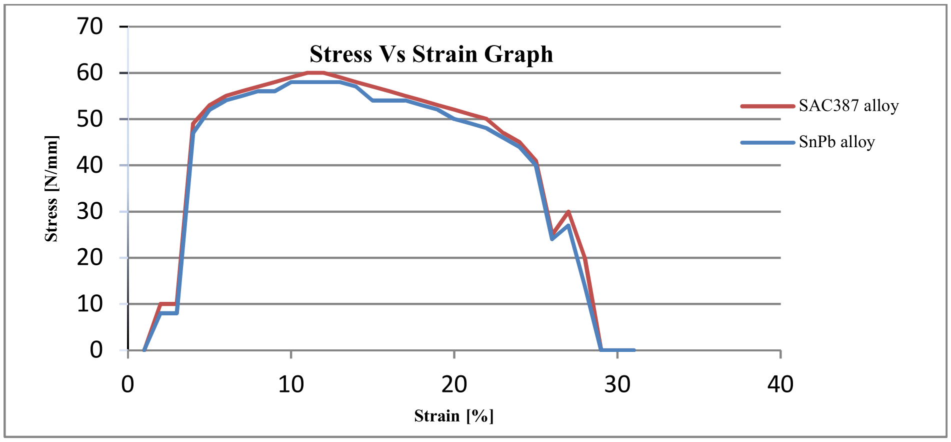


Fig 7. SAC387 and SnPb tensile test graph.

Table II
Tensile test specimen details and tensile test of SAC387 and SnPb

Test Name	Tensile testing	Thickness	2.0 mm
Test Speed	1.0 mm/min	Length	30.0mm
Width	7.0 mm	-	-

TEST NO. 1 SAC387 alloy		TEST NO. 2 SnPb alloy	
AREA (MM^2)	7.0000	AREA (MM^2)	7.0000
DIAMETER (mm)	7.0000	DIAMETER (mm)	7.0000
ELONG. @ BREAK (mm)	8.2400	ELONG. @ BREAK (mm)	8.5400
ELONG. @ PEAK (mm)	2.5930	ELONG. @ PEAK (mm)	2.4930
ELONG. @ YIELD (mm)	0.6040	ELONG. @ YIELD (mm)	0.5980
ENERGY @ BREAK (N.m)	5.5736	ENERGY @ BREAK (N.m)	5.4736
ENERGY @ PEAK (N.m)	1.6365	ENERGY @ PEAK (N.m)	1.4365
ENERGY @ YIELD (N.m)	0.0813	ENERGY @ YIELD (N.m)	0.0783
LOAD @ YIELD (N)	121.0000	LOAD @ YIELD (N)	119.1000
LOAD @ YIELD (N)	887.0000	LOAD @ YIELD (N)	875.0000
LOAD @ YIELD (N)	249.0000	LOAD @ YIELD (N)	246.0000
PLASTIC STRAIN @ BREAK (%)	27.8800	PLASTIC STRAIN @ BREAK (%)	26.9800
STRAIN @ BREAK (%)	27.4670	STRAIN @ BREAK (%)	25.4670
STRAIN @ PEAK (%)	8.6433	STRAIN @ PEAK (%)	8.4433
STRAIN @ YIELD (%)	2.0133	STRAIN @ YIELD (%)	2.0003
STRESS BREAK @(N/mm^2)	-8.2313	STRESS BREAK @(N/mm^2)	-7.6313
STRESS PEAK @(N/mm^2)	60.3400	STRESS PEAK @(N/mm^2)	58.3400
STRESS YIELD @(N/mm^2)	16.9390	STRESS YIELD @(N/mm^2)	15.8390
YOUNG MODULUS (N/mm^2)	1989.9000	YOUNG MODULUS (N/mm^2)	1977.9000

IV. CONCLUSION

In this study, microstructure evaluation and mechanical properties of 95.5%Sn-3.8%Ag-0.7%Cu (SAC387) have been presented. We observed that the microstructure of SAC387 comprised of tin (Sn) matrix and intermetallic compounds of Cu6Sn5 and Ag3Sn. The thickness size of both Cu6Sn and are increase with increasing of thermal aging time. The higher environmental temperature, then there will be the shorter lifetime of a circuit board. This behavior is strongly connected with IMCs sizes because IMCs size and layer increase with the increase in aging time and temperature. Another reason for high strength is the large fraction of IMCs particles. The tensile tests were performed to measure strength of SAC387 and SnPb. The yield strength and tensile strength of lead-free solder material are more than tin-lead soldering material.

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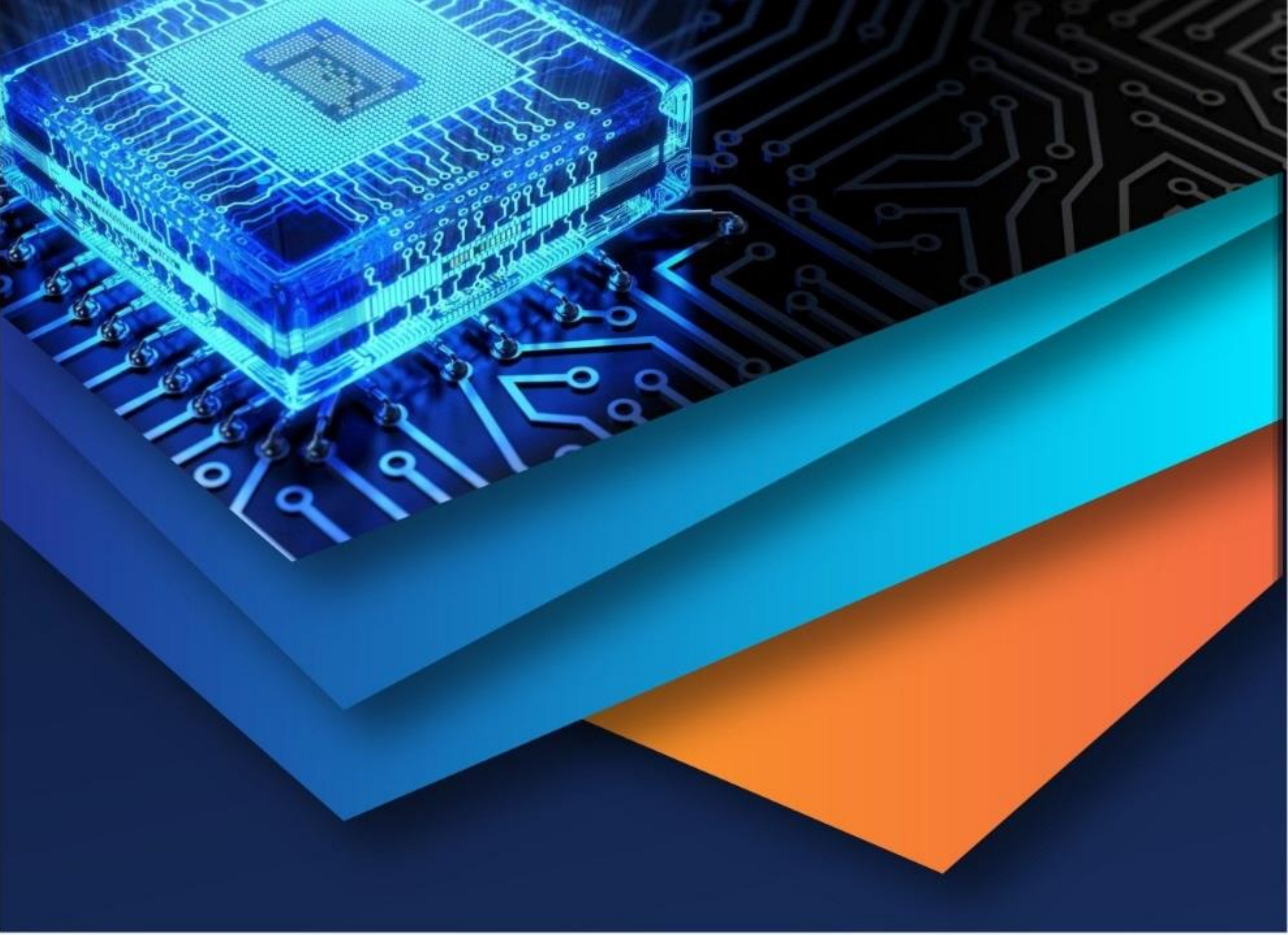

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