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Effect of Aging Time on Deformation Behavior of Lead-Free and Lead Base Solders Alloys

Abstract- *The effect of aging time on the deformation behavior of lead-free and lead- based sub-mm solder alloys were investigated. Experimental results showed that the aging time (less than 4 hours) did not have any effect on the anisotropy behavior of Tin solder balls during compression processes but that is clear in other intervals time specially when the aging time increased, and the microstructure images show different grain growth in high temperature longer time and the Tin anisotropic behavior in lead-free solder alloys*

Keywords- *Data Mining, ID3 algorithm, Entropy, Decision Tree.*

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1. Introduction

Recently, there have been many investigations regarding the mechanical properties of the lead-free solders [1,2]. However, there is lack of understanding about the mechanical properties of these alloys. The existing information in the literature for different fabrication and testing process causes variation in microstructures and mechanical properties associated with these microstructures [3-6]. Therefore, in order to develop a reliable model to predict the deformation behavior of lead-free solders, a comprehensive understanding of mechanical properties is required. Most of the prior studies focus on the tin anisotropy and the effect of this material characteristic on mechanical properties of lead-free solder joints and their behavior during mechanical deformation and thermal processes [7-10].

Comprehensive understanding of mechanical properties is required to develop a reliable model to predict the deformation behavior of lead-free solders [11-13].

Aging study of (Sn-Ag-Cu) solder alloys and Lead-based has been performed in order to evaluate micro structural changes between the different solders alloys [14-16].

It is very important to understand the impact of Isothermal aging on the long-term behavior of lead-free solder, which operate in environments branches [17].

There are very large discrepancies in both lead-free and Sn-lead solder alloys [18]. Data bases mechanic measurement of isothermal aging effects and the resulting changes in materials behavior of lead-free and lead- based solder were performed and analyzed to determine the impact of isothermal aging, is very important on mechanical properties [19-20].

Modern electronic are subjected to several thermal conditions. Moreover, many assemblies are composed of different electronic materials with a wide range of thermal expansion coefficient, which causes extra stress generation [21-22]. Additional work ought to be done to improve the scientific understanding variable properties of solder balls for different alloys as lead –free and lead based solder alloys, so the motives of the present study are to give more understanding how the aging time effect with different balls sizes on Sn elastic and plastic anisotropy phenomena and its effect on the strength of solder during compression deformation, and also in microstructure changes of the alloys.

Such lead-free solder alloys behavior is very important for the harsh application environments present in high performance computing, and in automotive, aerospace, defense applications, and in electronic printed circuit industry.

2. Experimental Procedures

I. Ageing process

Lead-based and lead-free solder alloys (Table 1), were studied, evaluating more than 300 balls that were (420-600) micron in diameter.

Table 1: Mechanical properties of tin-lead and lead-free solder alloys

Chemical Composition	Melting Temperature ˚C	Young s Modulus GPa	UTS MPa
SAC305	217	54	53
Sn42Bi58	138	11.9	63
SAC307	217	51	48
30Sn70Pb	185	32	42

The selected aging temperature is 85C for Sn42Bi58 and (150) C for other alloys at a different aging time of 1, 4, 24, 48, and 72 hours. Specimens are exposed to these conditions in a Carbolite temperature control Oven, type 3508. After each interval aging time, a certain numbers of balls for each alloy were exerted for two tests. The first tests for compression process taken about 20 balls from each alloy for one interval aging time and another group of balls for the second test of microstructure analysis. The rest of balls for all groups put back again into the Oven. Same procedures were repeated for 4, 24, 48, 72 hours. Aging experiments were performed by placing the solder alloy balls in one plate for each group of solder balls (SAC305, Sn42Bi58, SAC307, and 30Sn70Pb).

II. Compression process

After each aging process, each ball was put in place on the loading platens of Rheometric Solids Analyzer instrument model RSS 111 (Figure 1) at room temperature. The ball solder alloys investigated in this study include the commercially available solder alloys, different samples of each alloy were aged to a set of conditions.

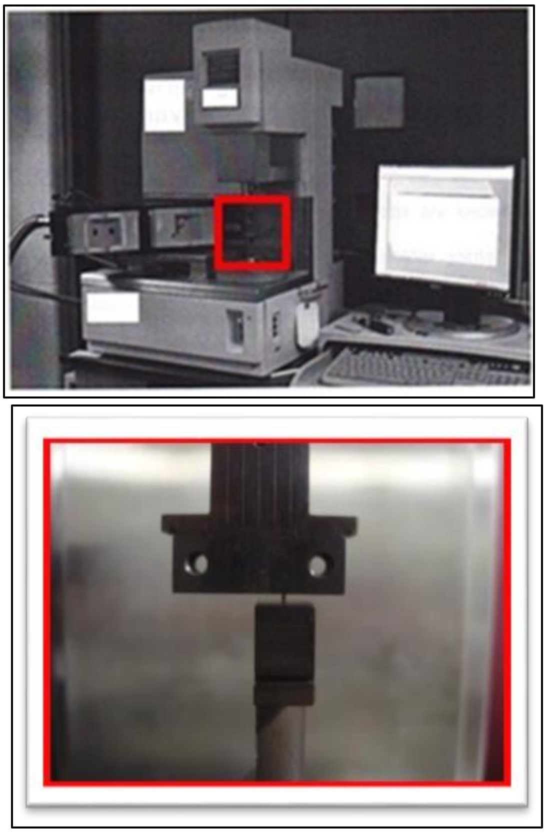

Figure 1: Ball compression fixture within Rheometric Solids Analyzer machine (Compliance 6.996E-05 mm/gm.)

III. Microstructure testing

To investigate the effect of grain size on the loading for different aging time the specimens of each composing were mechanically polished with silicon discs as well as 6-micron, 3-micron, and 1-micron diamond pastes. Chemical etching was performed for few seconds using 5% of hydraulic acid and 95% ethanol solution. The microstructure of selected balls for different aging time was investigated after the polishing of balls and scanning by Scanning electron microscopy, which was employed to characterize the microstructures of the samples and crystal graphic orientation of grain to provide a detailed characterization of the deformation behavior in Lead-Free solders alloy (SAC30, SAC307, and Sn42Bi58) and Lead-based solder alloy 30Sn70Pb samples after compression test for different aging time. Optical and Polarized images for each alloy microstructure have been done and all are illustrated in Figure 41 to Figure 80.

3- Results and Discussion

I. Aging time effect on solder alloys deformation behavior

During compression, processes various deformation behavior occurred which represent the variation in the mechanical property variability for different alloys. This significantly clear in loading-Unloading processes and in maximum-Loading processes after different aging time. Figure 2 for aging time less than 4 hours inhibited no effect in tin deformation behavior in the loading-Unloading curves of SAC305 alloy, but when increasing the aging time for 4, 24, 48 and 72 hours representative in Figures 3, 4, 5, and 6 in Loading-Unloading curves, tin anisotropic deformation behavior inhibit clear specially after 72 hours aging time (Figure 6) represented by samples No. 6, and No. 8.

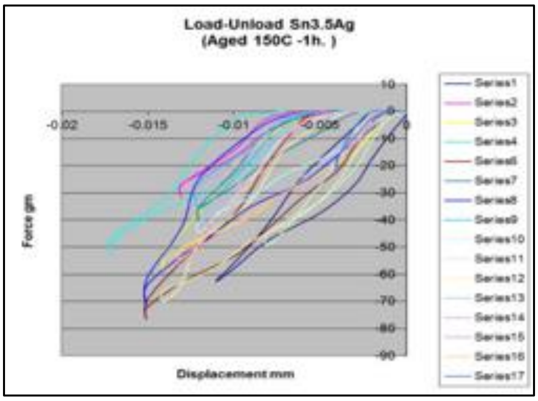

Figure 2: Load-unload, Aged 150C- 1hr

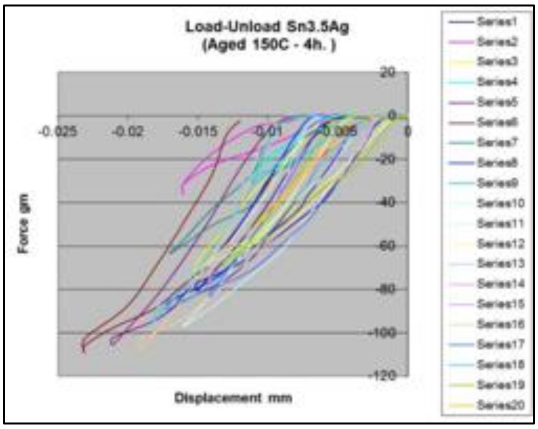

Figure 3: Load-unload, Aged 150C- 4hrs

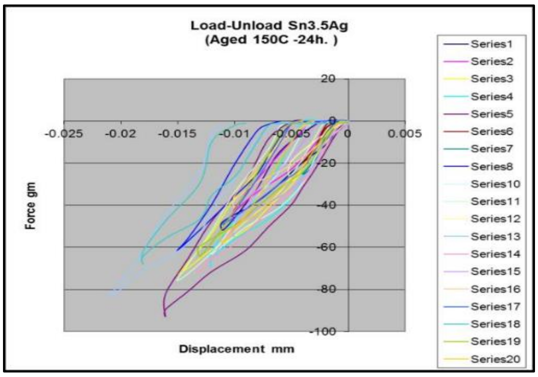

Figure 4: Load-unload, Aged 150C- 24hrs

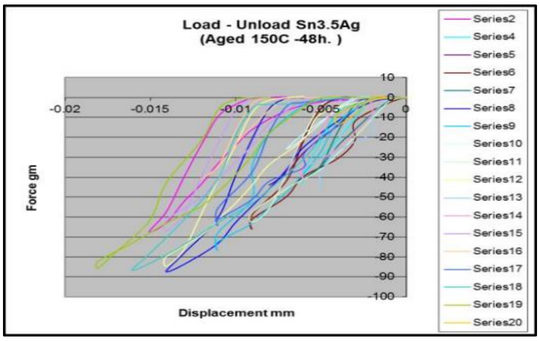

Figure 5: Load-unload, Aged 150C- 48hrs

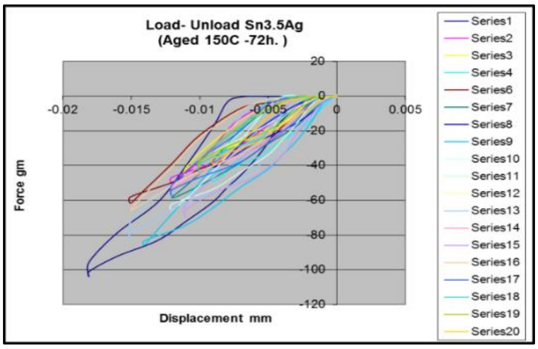

Figure 6: Load-unload (Aged 150C- 72hrs

This clear also in Figures7, 8, 9, 10, and 11 for Maximum Deformation for the same alloy and tin deformation behavior for the same samples especially for aging time of 72 hours at 150 C (Figure 11).

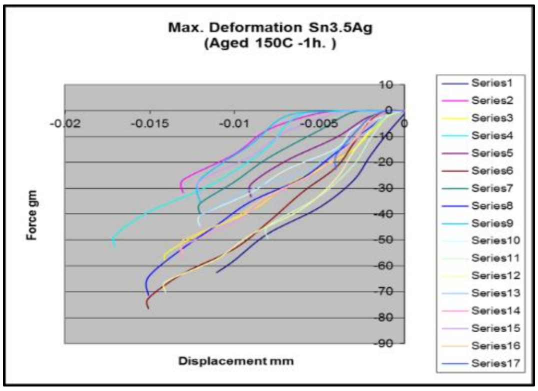

Figure 7: Max. Def. Aged 150C- 1hr

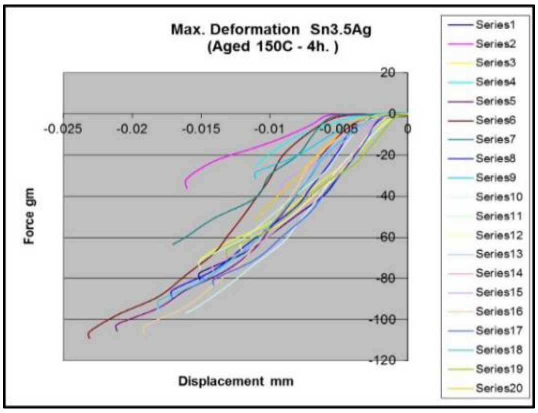

Figure 8: Max. Def. Aged 150C-4hrs

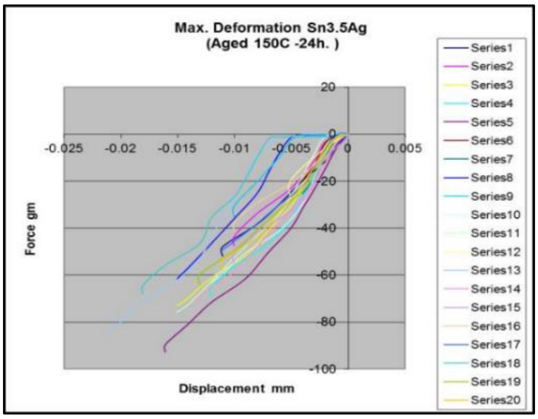

Figure 9: Max .Def. Aged 150C- 24hrs

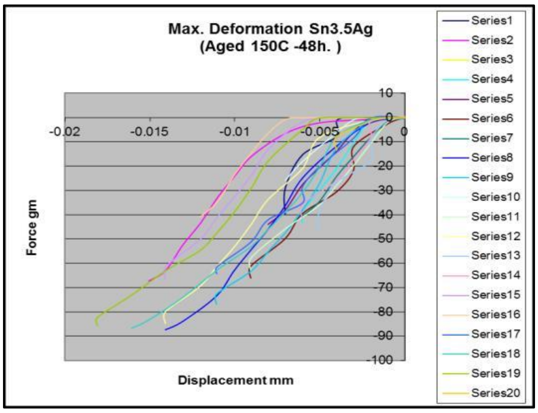

Figure 10: Max. Def. Aged 150C- 48hrs

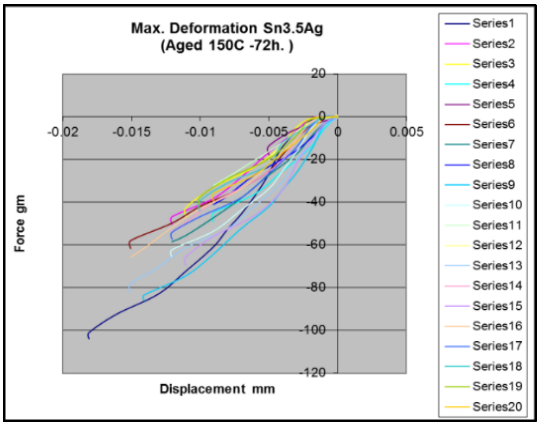

Figure 11: Max. Def. Aged 150C- 72hrs

Same behavior for tin in Sn42Bi58 alloy shows in Figures12, 13, 14,15, and 16 for loading – unloading, the anisotropic behavior of tin inhibit very clear for samples No. 15 and No. 19 in Figure 16 after aging time of 72 hours.

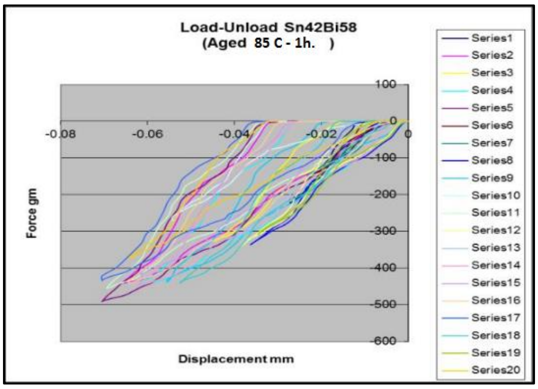

Figure 12: load-unload Aged 85C-1h

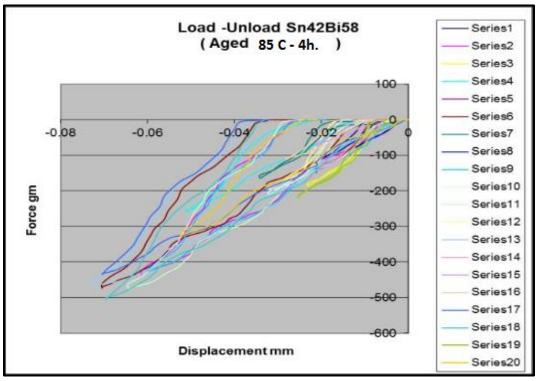

Figure 13: Load-unload Aged 85C- 4hrs

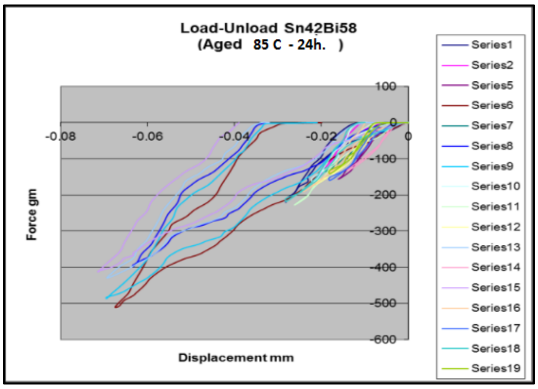

Figure 14: Load-unload Aged 85C- 24hrs

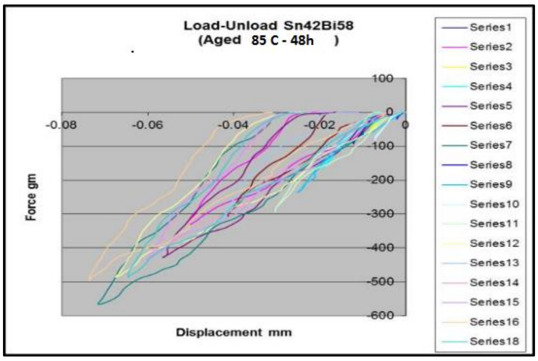

Figure 15: Load-unload Aged 85C- 48hrs

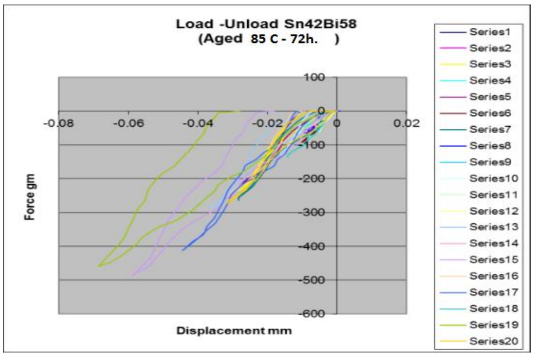

Figure 16: Load-unload Aged 85C- 72hrs

Max.-load deformation in Figures 17, 18, 19, 20, 21 emphasis this behavior which is clear in Figurer 21 for same samples No.15 and No. 19.

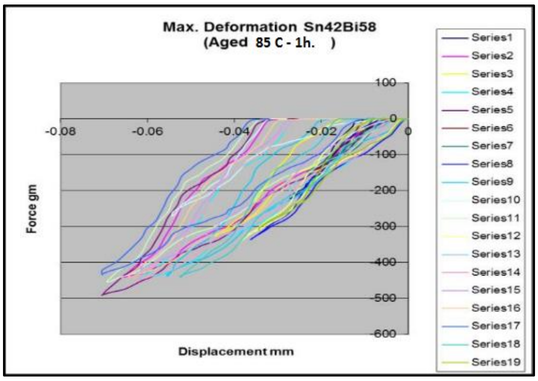

Figure 17: Max. Def. Aged 85C- 1h

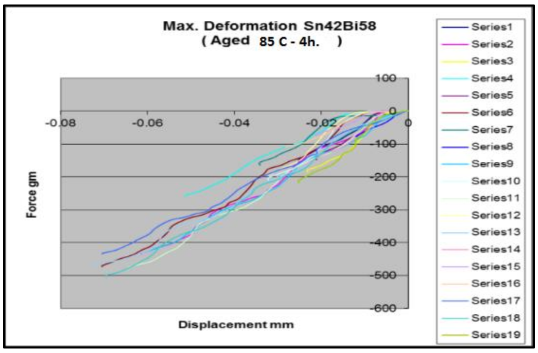

Figure 18 Max. Def. Aged 85C- 4hrs

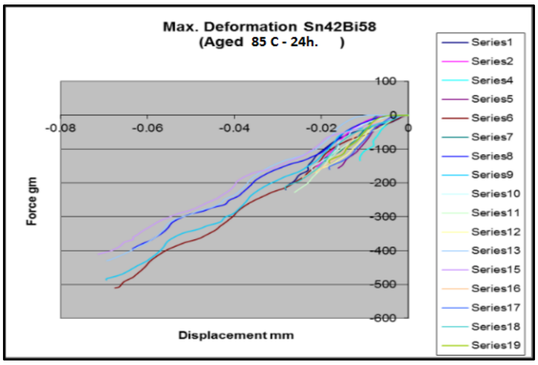

Figure 19: Max. Def. Aged 85C- 24hrs

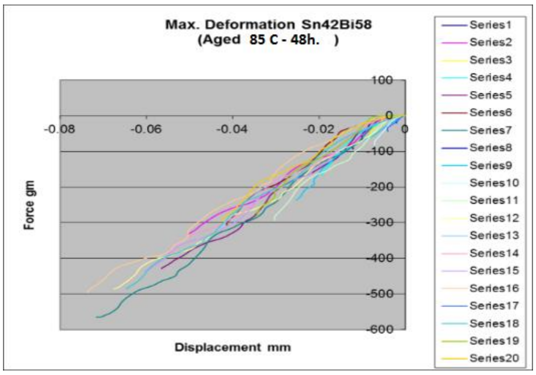

Figure 20: Max. Def. Aged 85C- 48hrs

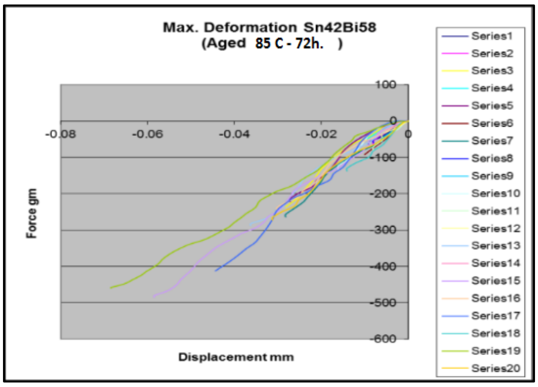

Figure 21: Max. Def. Aged 85C- 72hrs

SAC307 alloy shows tin behavior in Loading – Unloading in Figures 22, 23, 24, 25, and 26. Sample No. 7 (Figure 23) shows different behavior than others samples after aging time for 4 hours, and same for series 4, and series 15 in Figure 25 after 48 hours and same samples inhibit same behavior in Max. Deformation in Figure 27 to Figure 31.

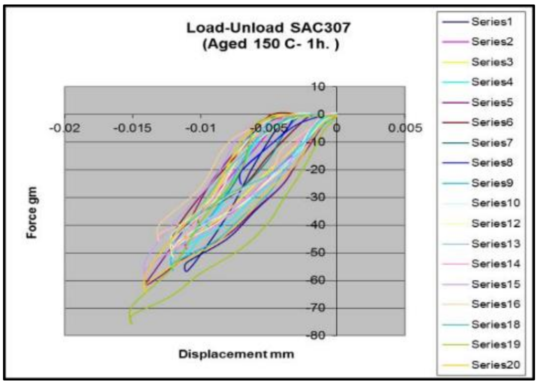

Figure 22: Load-unload Aged 150C- 1h

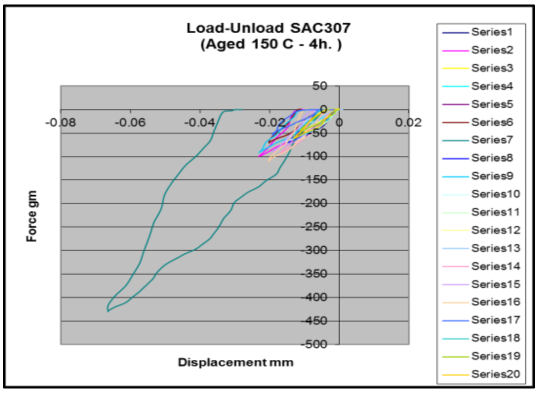

Figure 23: Load-unload Aged 150C- 4hrs

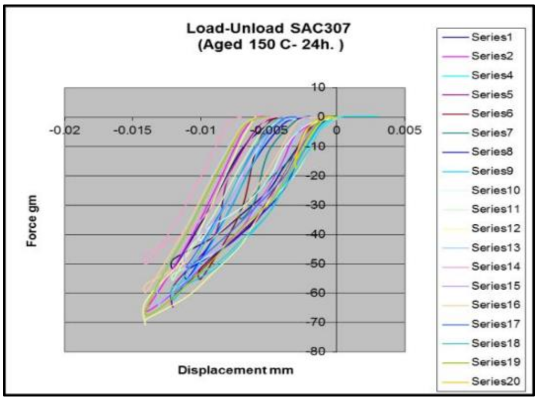

Figure 24: Load-unload Aged 150C-24hrs

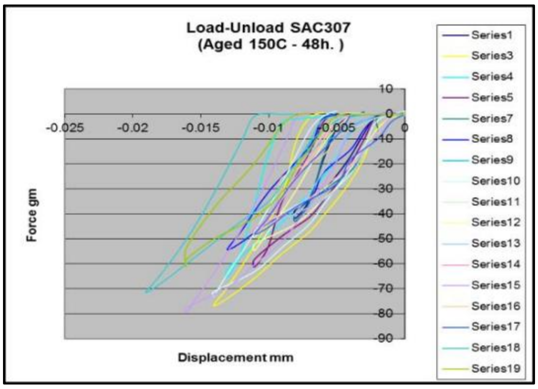

Figure 25: Load-unload Aged 150C- 48hrs

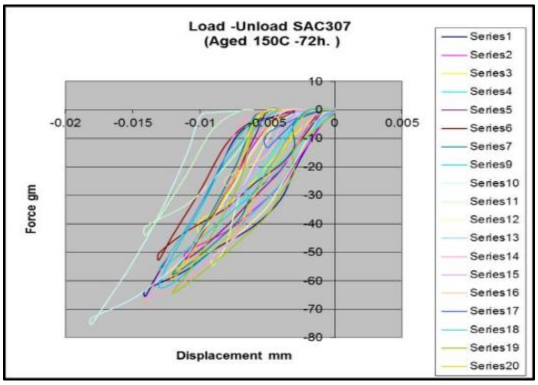

Figure 26: Load-unload Aged 150C- 72hrs

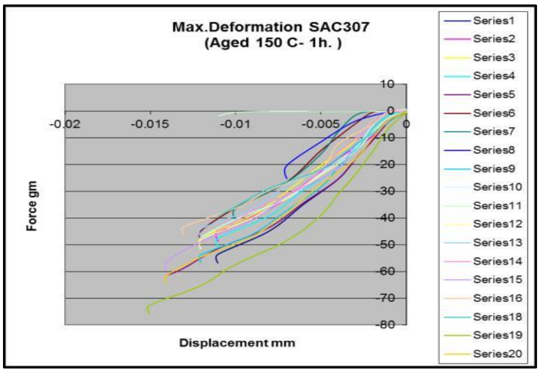

Figure 27: Max. Def. Aged 150C- 1hr

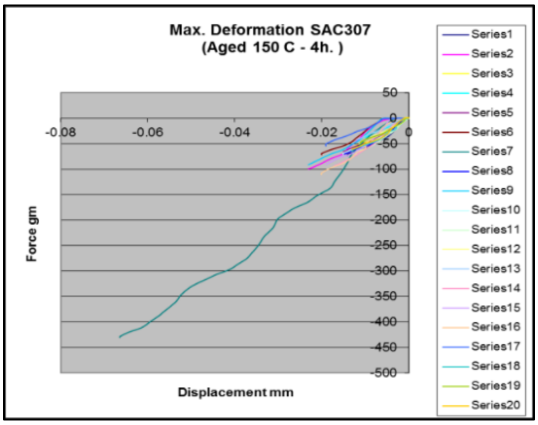

Figure 28: Max. Def. Aged 150C- 4hr

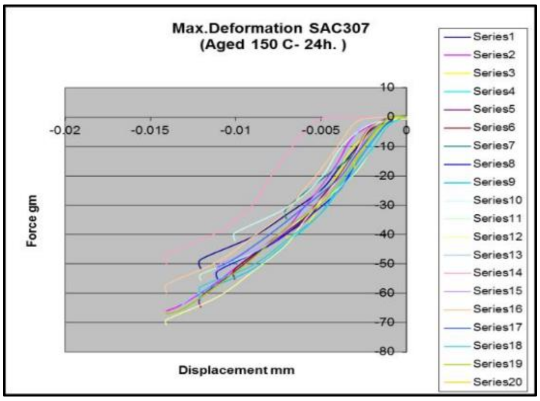

Figure 29: Max. Def. Aged 150C- 24hrs

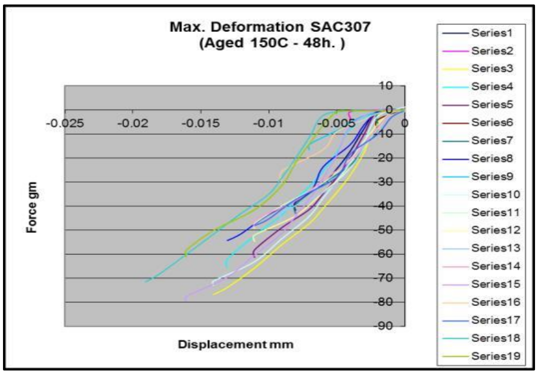

Figure 30: Max. Def. Aged 150C- 48hrs

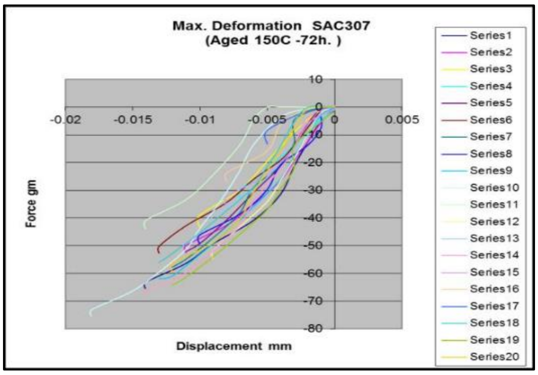

Figure 31: Max. Def. Aged 150C- 72hrs

The loading- unloading deformation for r Sn37Pb (Lead-based alloy) in Figures 32, 33, 34, 35, and 36, and Max- deformation for the same alloy in Figure 37, 38, 39, 40, and 41. All show similar deformation behavior for all samples after different aging time and have no clear effect of tin behavior.

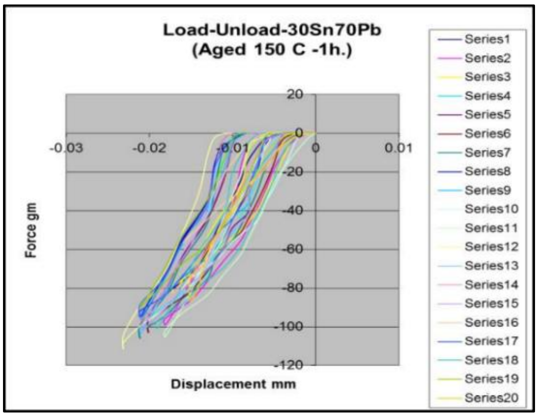

Figure 32: Load-unload Aged 150C- 1hrs

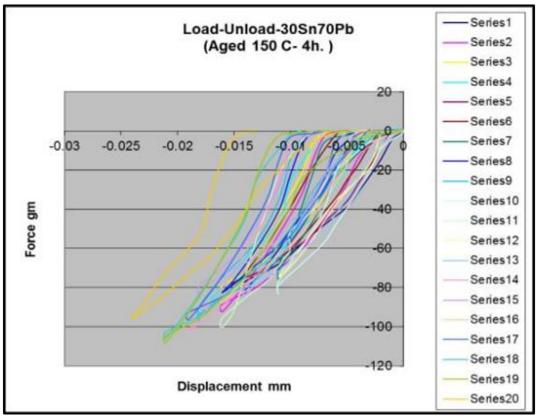

Figure 33: Load-unload Aged 150C- 4hrs

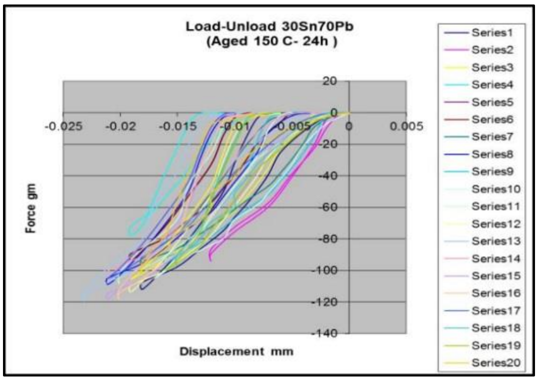

Figure 34: Load-unload Aged 150C- 24hrs

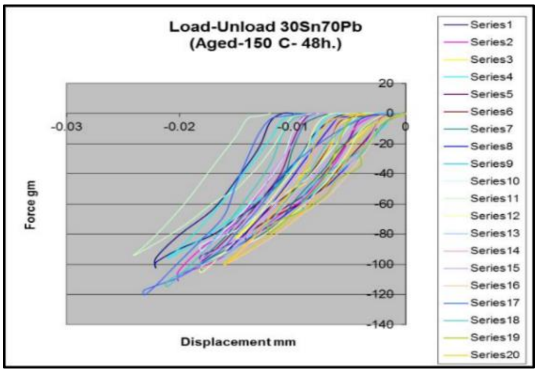

Figure 35 Load-unload Aged 150C- 48hrs

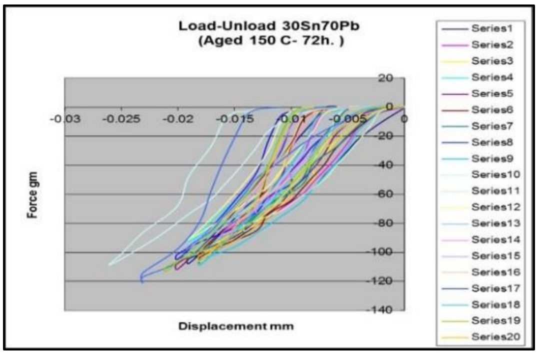

Figure 36 Load-unload Aged 150C- 72hrs

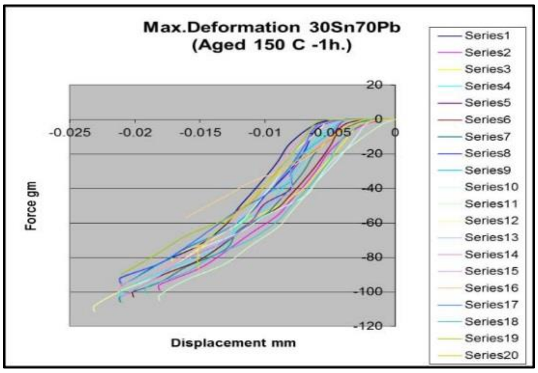

Figure 37 Max. Def. Aged 150C- 1hr

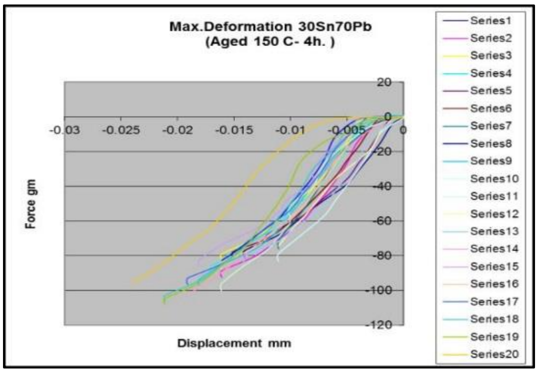

Figure 38 Max. Def. Aged 150C- 4hrs

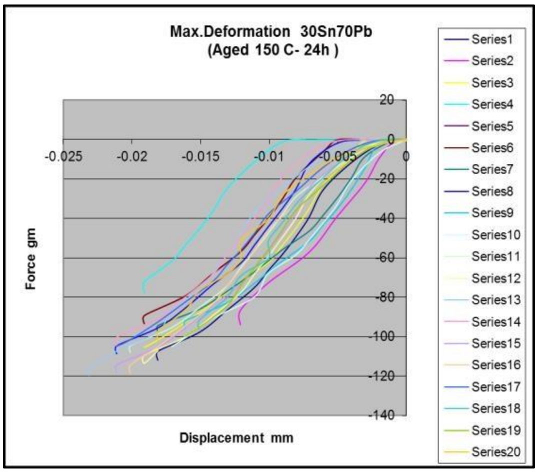

Figure 39 Max. Def. Aged 150C- 24hrs

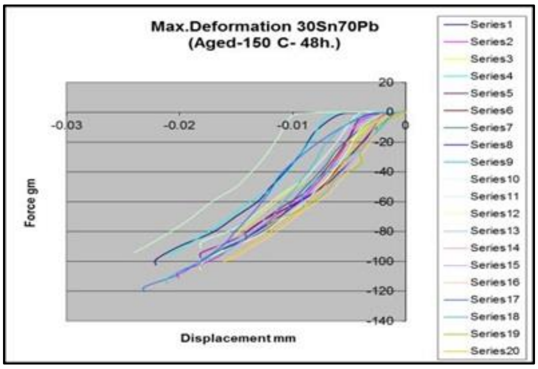

Figure 40 Max. Def. Aged 150C- 48hrs

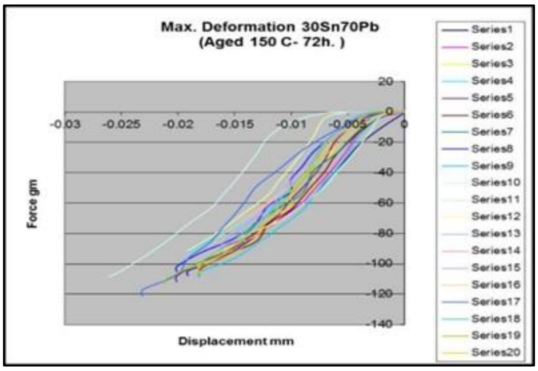

Figure 41 Max. Def. Aged 150C- 72hrs

II. Aging time effect on solder alloys microstructure

Scanning images of microstructure of lead-free and lead–base by SEM illustrated the grains distribution, Figure 42, 43, 44, 45, and 46 show the optical images for SAC305 solder alloy. The black zone is the matrix mainly composed of Sn and the white particles, rich in Ag and Cu are brittle in nature in comparison with the soft Sn matrix and affect the mechanical properties of Lead-Free solder. Microstructure of alloy after more than 24 hour aging time shows coarsening in both of Ag and Sn particles and enlarging of grain size, this more clear in Figure 46 for aging time of 72 hours. The polarized images for the same alloy (Figures 47, 48, 49, 50, and 51) show same behavior of Sn particles, and the orientation of tin after aging time than 4 hours inhibit its anisotropic phenomena as illustrated in Figures 49, 50, and 51.

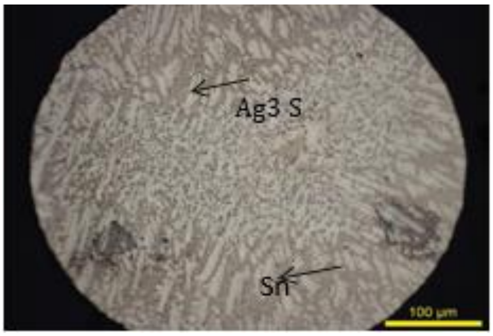

Figure 42: SAC305-Optical-1hrs

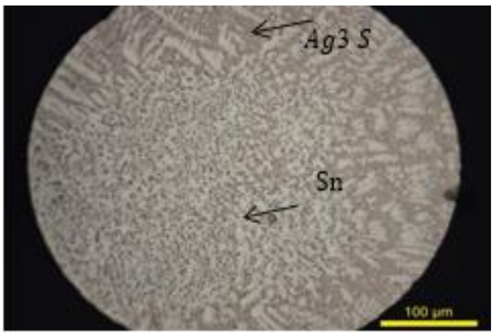

Figure 43: SAC305-Optical-4hrs

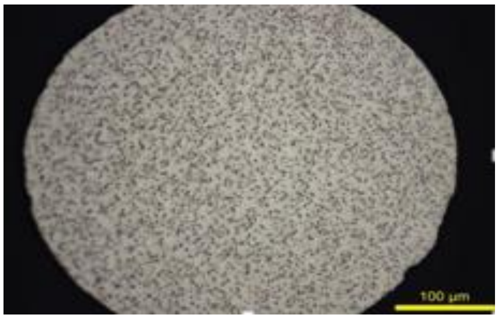

Figure 44: SAC305-Optical-24hrs

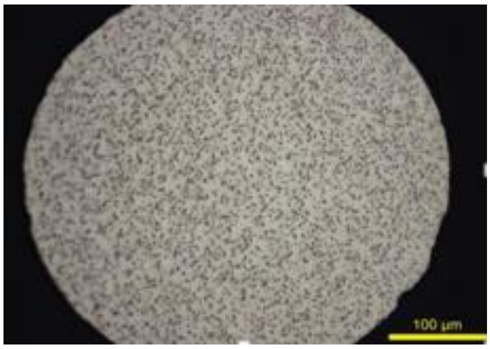

Figure 45: SAC305-Optical-48hrs

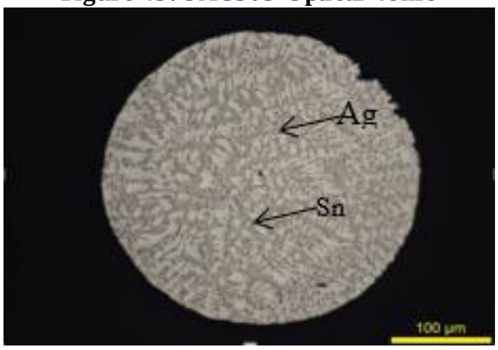

Figure 46: SAC305-Optical-72hrs

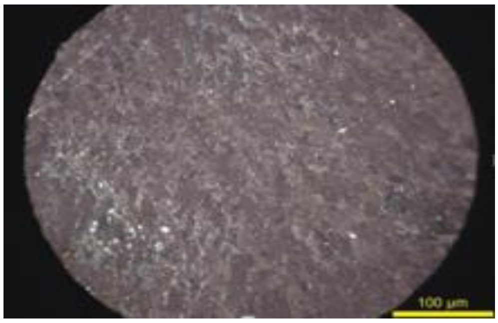

Figure 47: SAC305-Polarized- 1hr

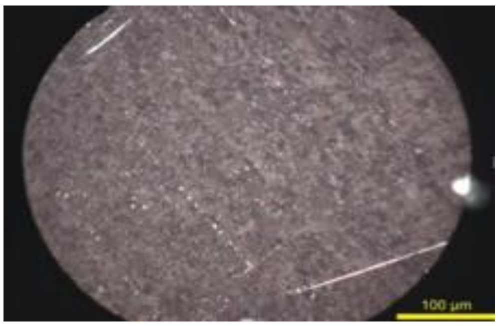

Figure 48: SAC305-Polarized-4hrs

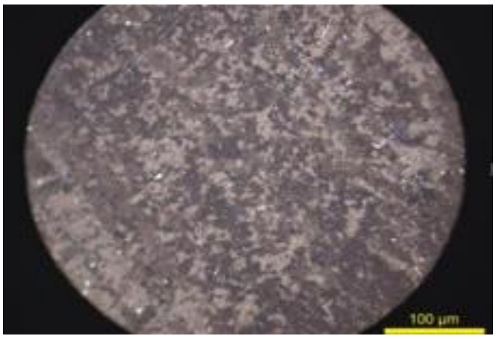

Figure 51: SAC305-Polarized-72hrs

For Sn42Bi58 solder alloys are shown in Figures 52 to 56 optical images and Figure 57 to 61 polarized images for different thermal aging times, coarsening of both Sn and Bi take place at rate depending on the aging time. It is clear from the micrographs that the coarsening of grains for aging time more than 4 hours and that can be shown in optical image (Figure 56) for 72 hours thermally aged time, that also confined with the Figure 57 to 61 of polarized images which inhibited significantly the orientation of tin particles after aging time.

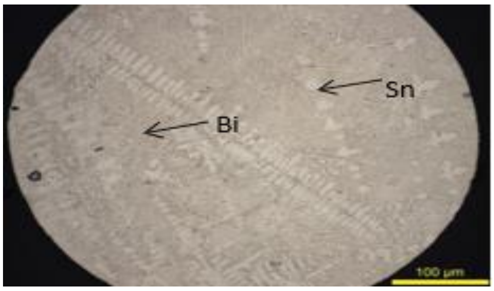

Figure 52: Sn42Bi58-Optical-1hr

Figure 53: Sn42Bi58-Optical-4hrs

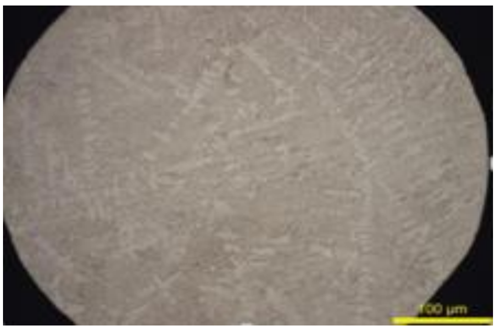

Figure 54: Sn42Bi58-Optical-24hrs

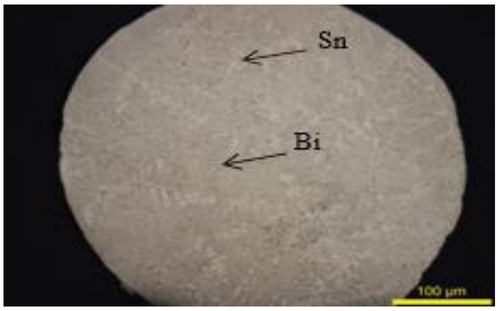

Figure 55: Sn42Bi58-Optical- 48hr

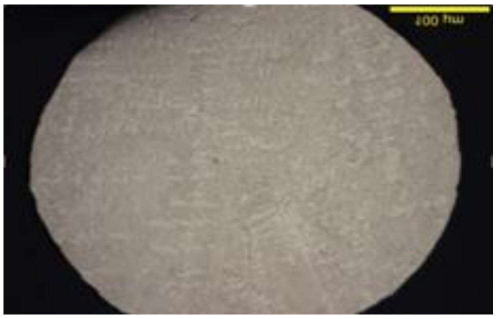

Figure 56: Sn42Bi58- Optical-72hr

Figure 57: Sn42Bi58-Polarized-1hr

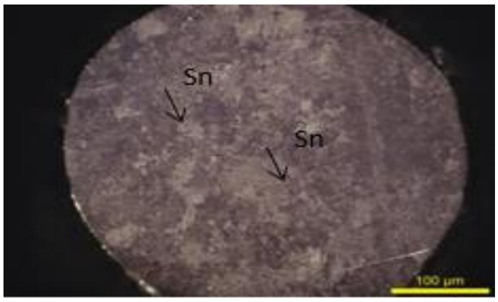

Figure 58: Sn42Bi58-Polarized-4hrs

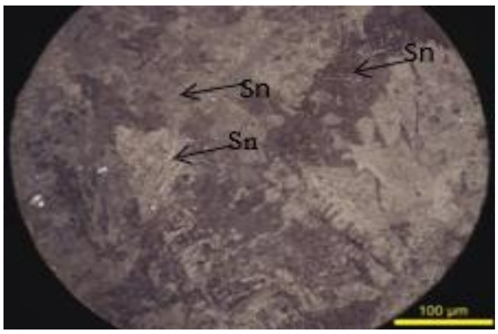

Figure 59: Sn42Bi58-Polarized- 24hrs

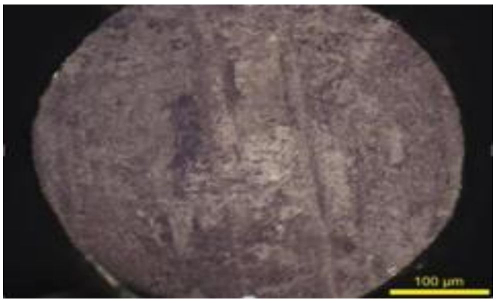

Figure 60: Sn42Bi58-Polarized-48hr

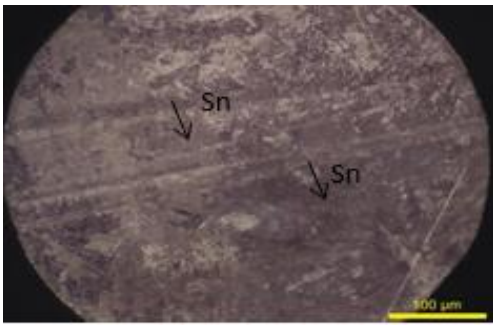

Figure 61: Sn42Bi58-Polarized-72hrs

SAC 307 solder alloy represents same behavior of lead free solder alloys mentioned above and that is showed in Figures 62 to 66 optical images and Figures 67 to 71 polarized images , shows three large regions with different colors(corresponding to no more than three main Sn grain orientations) after 72 hours aging time (Figure 71).

The Lead- Free alloys solders under age softening with increasing aging time up to three days. This suggests that the initial age softening of Sn w a s due to strong microstructure coarsening. However as the aging time increases from 1 day the alloy becomes harder. This correlates with the dispersion of fine Ag-Sn intermetallic particles into the tin-rich solid solution crystals.

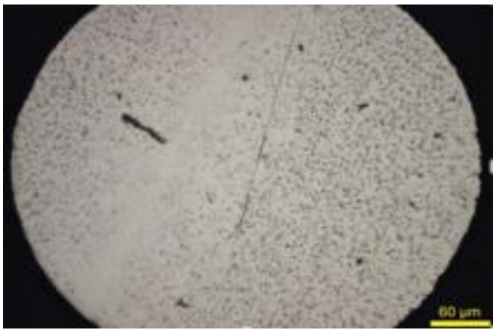

Figure 62: SAC307-Optical-1hr

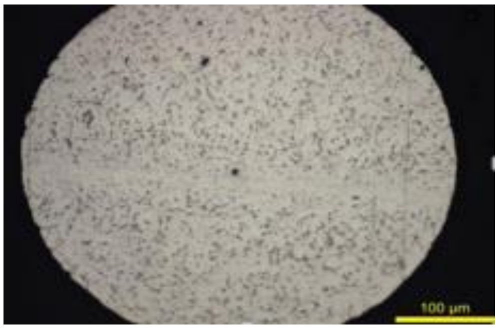

Figure 63: SAC307-Optical-4hrs

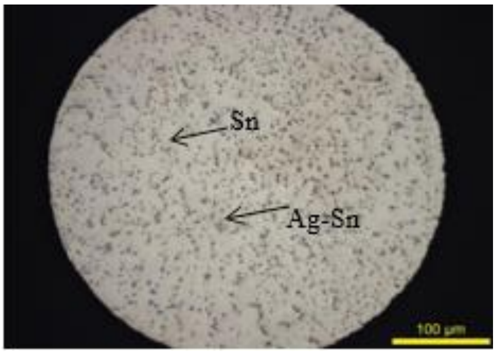

Figure 64: SAC307-Optical-24hrs

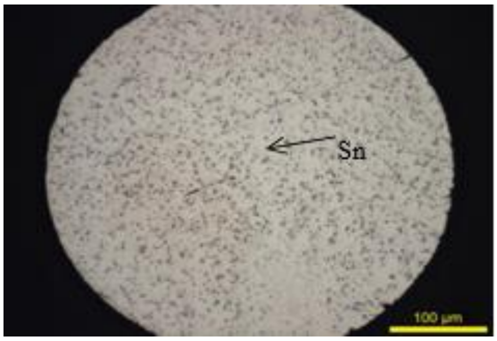

Figure 65: SAC307-Optical-48hrs

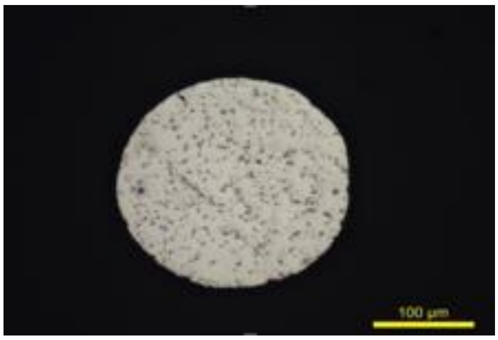

Figure 66: SAC307-Optical-72hrs

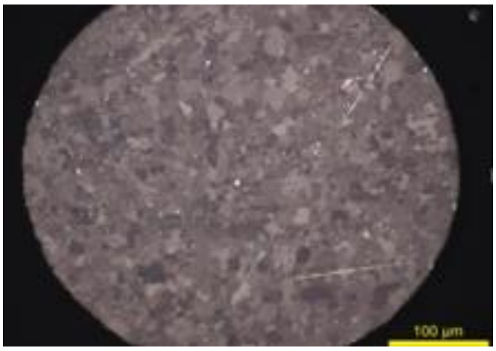

Figure 67: SAC307-Polarized-4hrs

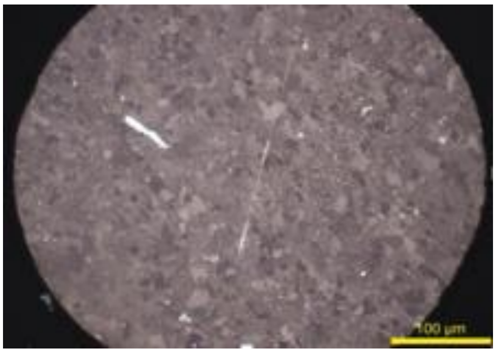

Figure 68: SAC307-Polarized-1hr

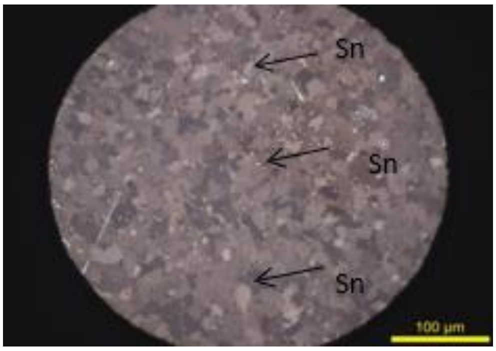

Figure 69: SAC307-Polarized-24hrs

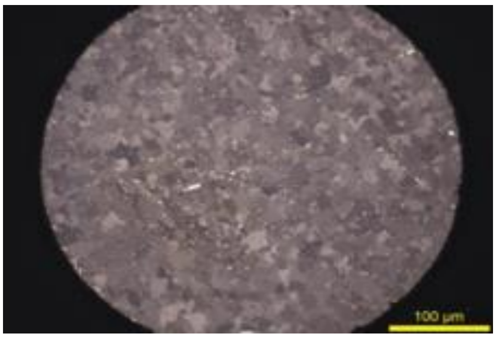

Figure 70: SAC307-Polarized-48hrs

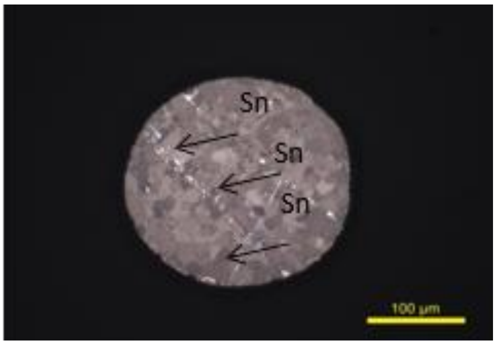

Figure 71: SAC307-Polarized-72hrs

The optical and polarized images of Lead-based solder alloy 30Sn70Pb microstructure Figures 72to 81 (a) shows alight region Sn-rich phase, participate particles, and dark particles of Pb, and show significantly ball microstructural changes and its stability under isothermal aging condition and coarsening of Sn particles. All images show no any changing in deformation behavior of tin after different aging time, which was shown before in Lead-free alloys behavior.

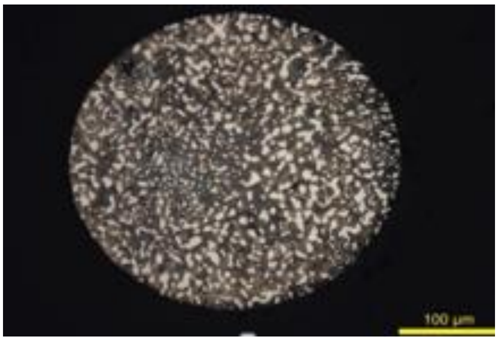

Figure 72: 30Sn70Pb-Optical-1hr

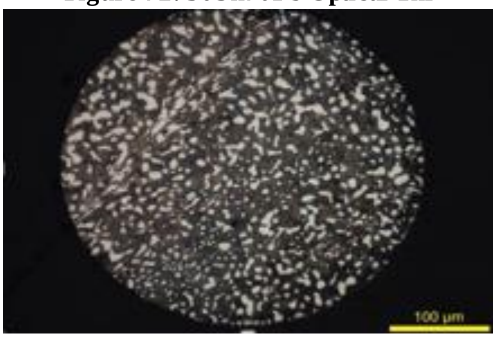

Figure 73: 30Sn70Pb-Optical-24hrs

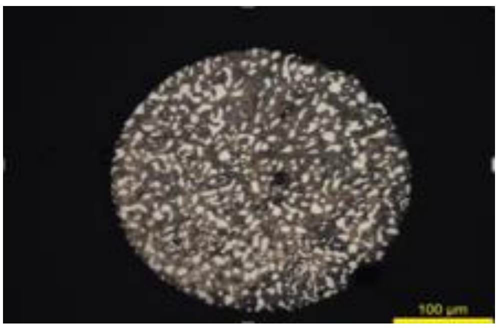

Figure 74: 30Sn70Pb-Optical-48hrs

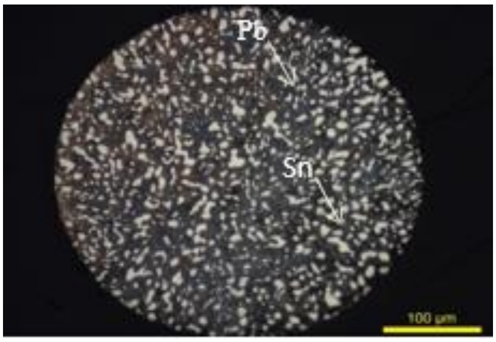

Figure 75: 30Sn70Pb-Optical-72hrs

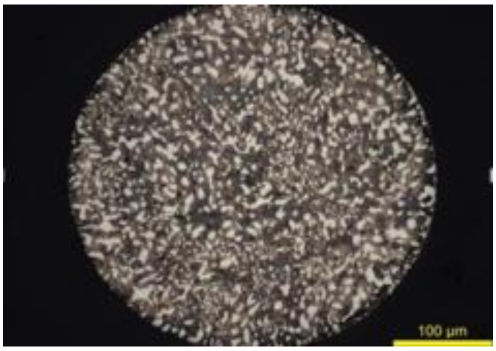

Figure 76: 30Sn70Pb-Polarized-1hr

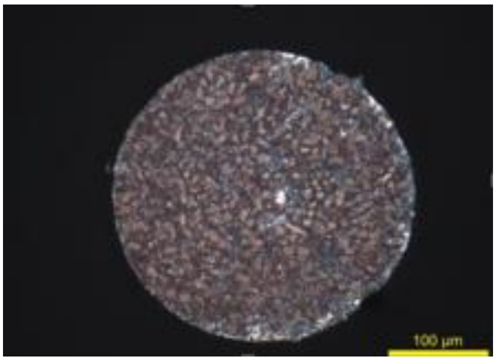

Figure 77: 30Sn70Pb-Polarized-4hrs

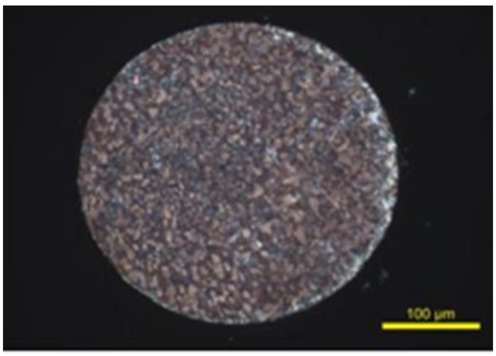

Figure 78: 30Sn70Pb-Optical-4hrs

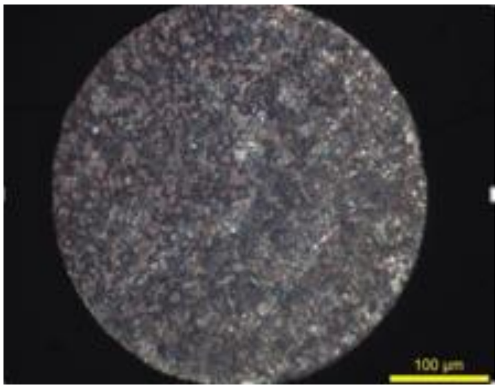

Figure 79: 30Sn70Pb-Polarized-4hrs

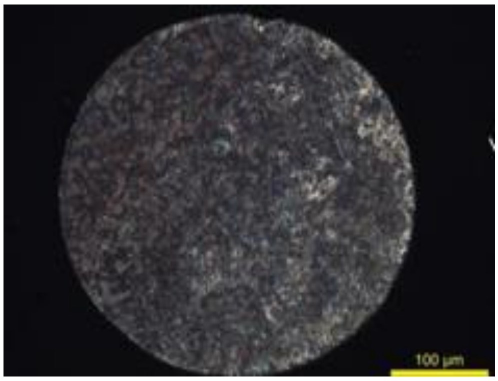

Figure 80: 30Sn70Pb-Polarized-48hrs

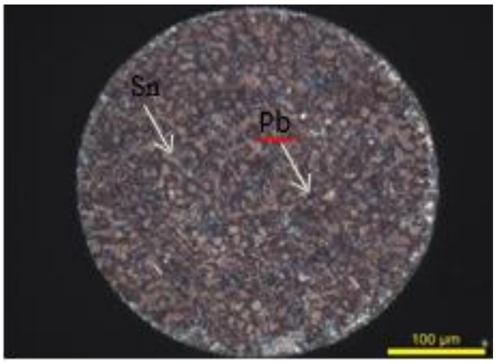

Figure 81: 30Sn70Pb-Polarized-72hrs

4- Conclusion

Different isothermal aging time at 85C and 150C of lead-base and lead-free alloys with compression deformation processes were done in order to get a comprehensive understanding the mechanical behavior of the solder balls. The followings conclusion can be supported by this work:

A - SAC305 as lead-free alloy balls inhibit during compression processes various mechanical properties for different aging times after more than 4 hours, some balls inhibit very clear the anisotropic phenomena tin during deformation processes.

The scanning images (SEM) for alloys supported the tin anisotropic behavior, the microstructure after more than 24 hours aging time shows coarsening in both Ag and Sn particles and the polarized images show the orientation of tin after aging time more than 4 hours which inhibit its anisotropic phenomena.

B- Same behavior can be seen for Sn42Bi58 alloy in compression processes after different aging time, after more than 24 hours aging time during compression, tin inhibits clearly anisotropic behavior and the polarized images show significantly the orientation of tin particles in larger aging time which supported alloy behaviors during a compression processes.

C- The third lead-free solder alloy SAC307 shows also same tin anisotropic behavior in compression processes and that is clear after aging time more than 4 hour to 72 hours and that is clear in polarized images which show three large regions with different color corresponding to no more than three main Sn grain orientation.

D- Sn37Pb as a lead-base solder alloy show different behavior than above mentioned lead-free alloys in each of compression deformation test and microstructure images for different aging time. Similar deformation behavior for all samples have no effect of tin behavior and its stability under different isothermal aging time show any changes in its behavior.

E- The different specification of manufacturing balls as received give different deformation behavior which effect on the mechanical proprieties and that must be taken into consideration by manufacturing and suppliers. Different isothermal aging time at 85C and 150 C of lead-base and lead free alloys.

Acknowledgment

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