Effects of Cooling Slopes in Lead Free Reflow

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Abstract
As more electronic assemblers move to lead free SMT production, concerns are raised over reflow cooling slopes and effects on solder joints. Due to the higher peak temperatures, cooling slopes are naturally more aggressive if not controlled properly. Impacts of variable cooling slopes should be considered for the transition to lead free assembly.

This paper evaluates the effect of variable cooling slopes on lead free solder joints. Controlled testing of lead free assemblies subjected to various cooling slopes in both air and nitrogen environments is also discussed. Solder joints will be inspected for solder joint grain structure under differing conditions of aggressive, medium, and mild cooling slopes. Data will be presented on the findings of this study along with suggestions of desirable cooling slopes and reflow system options to best support the reflow cooling profile.

Lead Free Transition
The transition to lead free electronics assemblies raises a considerable amount of questions that have been taken for granted in traditional lead material based SMT reflow. This transition challenges the industry to once again ask the questions when SMT reflow was first introduced.

A critical part of the lead free assembly transition is in the reflow process. Higher peak temperature requirements for the material now comes closer to critical peak temperature allowed by the component and board used within the assembly. The differing masses and materials used will absorb and release heat at differing rates that leads to differences in TCE (thermal coefficient of expansion) and can be a concern for final assembly quality and long-term reliability. Special care must be given in order to achieve proper soldering requirements at the balance of limiting stress and damage to the assembly.

Test Board Build
The dummy test boards utilized in the experiments are FR4 laminates, .062 thick with silver and gold selected as board finishes, fig 1. The board finishes selected were not the focus of the experiment but rather a representation of popular finishes utilized in lead free electronics assembly.

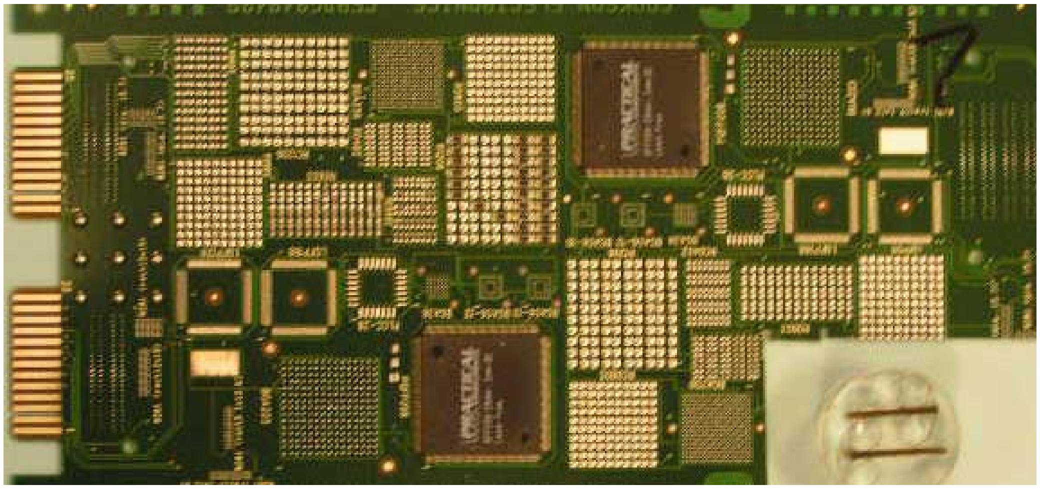

Fig 1 – Dummy test board example with cut away and mounted sample.

The lead free material utilized for the experiment is a SAC 305 from a worldwide material supplier. Profiles were developed utilizing the material supplier recommended parameters for development. It was noted that in the specification of the material the supplier suggested an aggressive cooling slope from 3-7°C/second from peak temperature with the most aggressive cooling slope preferred. This is an interesting note since other material suppliers have referenced cooling slopes from 2-4°C/second from peak temperature.

The focus of the study was to determine the affects on solder joint structure of different cooling slopes measured in degrees C per second from peak temperatures of the electronics assembly. A total of seven profiles were developed on an Electrovert OmniExcel 10 reflow system with Nitrogen inerting capability. Out of the seven profiles, three were selected that represented differing average cooling slopes of 6.31° per second, 3.91° per second, and 1.27° per second.

After development of the profiles, 12 samples were produced, six gold finish boards and six silver finish boards. The samples were then processed through the oven with differing cooling slopes in air and nitrogen environments. This produced a total of 12 samples that were each produced under the different parameters.

Sample Mounting and Preparation

Once the boards were processed, samples were cut of the 0402 resistors from the board for cross sections of the solder joints. Each sample was mounted and polished in order to analyze magnified views of the solder joints and grain structure. Fig 2 represents the mounting of the cross-sectioned sample ready for grinding, polishing and etching.

Fig 2 Sample mounting, ready for preparation

The samples were sent to Buehler Ltd. for grinding, etching, and image analysis. Grinding and polishing was a multi step preparation method. Starting with 400 grit abrasive and water as a lubricant the samples were ground to the desired level. The next steps involved 9µm and 3µm polishing abrasive with a METADI® lubricant. Final preparation method was a Mastermet® abrasive.

Once the samples were properly prepared they were each subjected to an etching process. Although attempted on all samples, the etching process was not successful for all. This process utilizes a 2% Nital solution in which the samples were immersed. The etching process allows a very clean surface for image selection and analysis. An image of each sample was taken under 50x or 100x magnification for analysis.

Sample Analysis

The samples were analyzed of the solder joint grain structure to determine the affects of the reflow environment and differing cooling slopes. Since the board finishes selected of gold and silver was not a focus of the paper, no further investigation was conducted on the affects of the finishes on the solder joint structure.

The first review was between the most aggressive cooling slope against the less aggressive cooling slope of the boards with the same finish and under the same reflow environment either air or nitrogen. This is represented in the following Fig 3 and Fig 4. In Fig 3 of the aggressive cooling slope, the bright Sn rich forms are more random in shape, form, and size. The lighter Sn rich forms are more diffused within the solder joint and represent a finer dendrite size. This result is expected in which rapid cooling solidifies the material prior to allowing full diffusion.

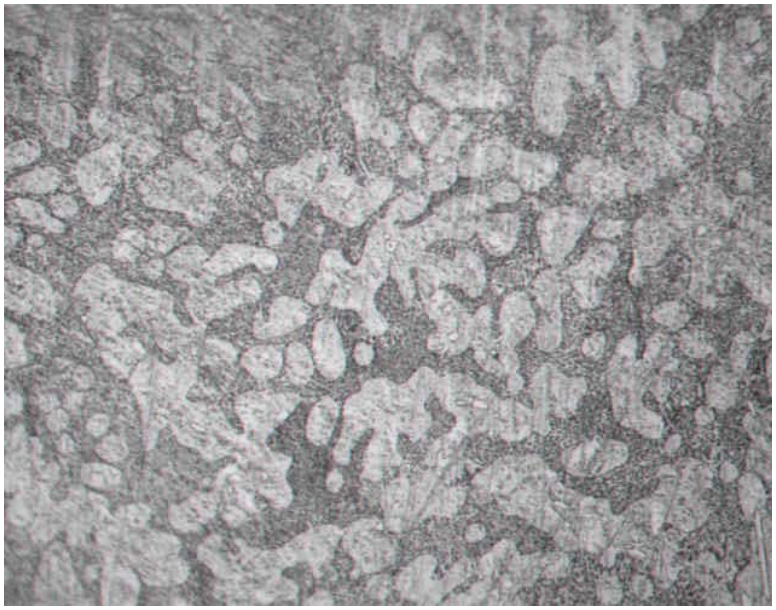

Fig. 3 -6.31° C/sec cooling reflowed in nitrogen environment, 50x magnification.

In Fig 4, Bright Sn rich forms appear longer and layered. Darker, eutectic forms show a longer growth formation, grainy in structure.

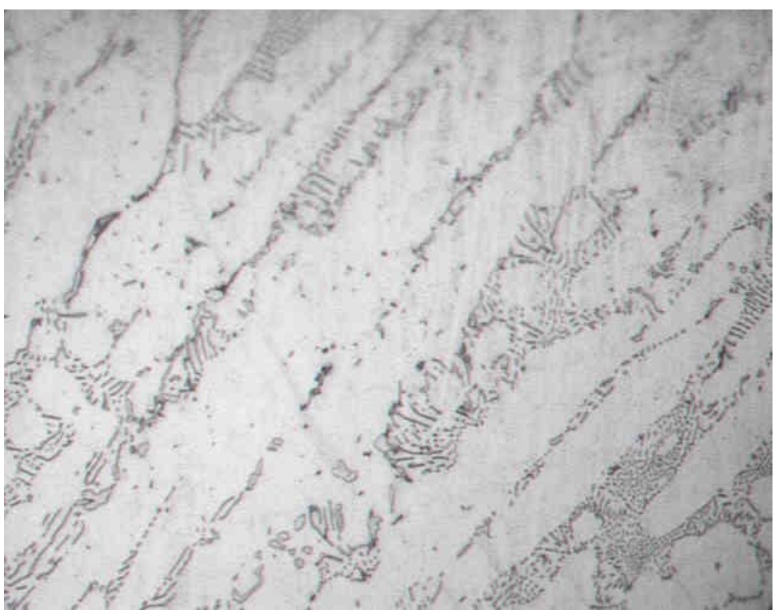

Fig. 4 –1.27° C/sec cooling reflowed in nitrogen environment, 50x magnification.

A review of a mild, medium-cooling slope was conducted to determine grain structure and size. It is interesting in the view of the solder joint that grainy "needle" like structures form within the darker, eutectic material along side the finer structures found in very aggressive cooling slopes. This sample also shows the formation of the longer, layering of the brighter, Sn rich forms. Fig. 5

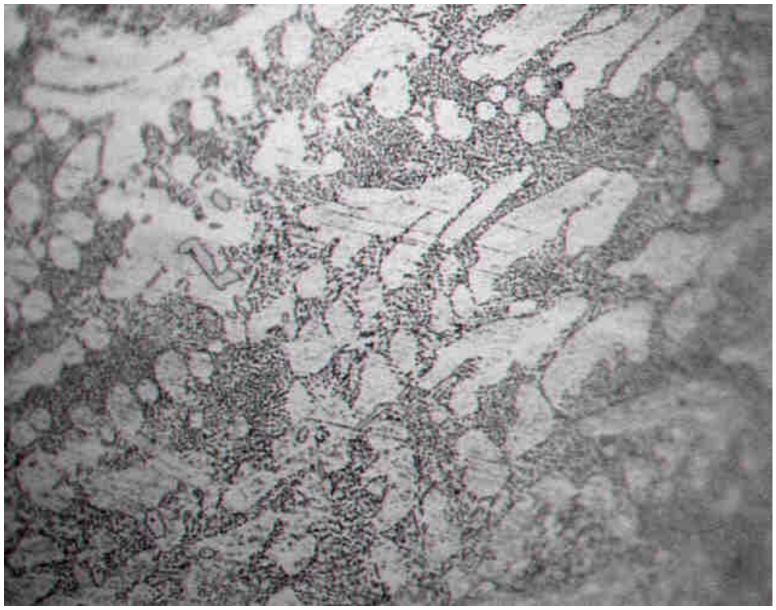

Fig. 5 –3.91° C/sec cooling reflowed in air environment, 50x magnification.

During the review of the samples a comparison of solder joints reflowed in air and nitrogen rich environments was conducted at the same cooling slope of –1.27°C/second. The samples obtained were in a polished condition with 50x magnification. In the comparison it was noticed that the air samples delivered slightly finer, darker, eutectic forms with more diffusion even though the cooling slope was very mild. The nitrogen samples nearly demonstrated the same results but it was noticed that the darker, eutectic forms began to have a linear shape. Although interesting, the results have been deemed inconclusive with polished samples. Clean etched samples with 100x magnification will be conducted for further analysis. It is also noticed, previous studies conducted within Speedline Technologies demonstrated that nitrogen only increases spreading of lead free material and has an insignificant affect on solder joint strength and structure.

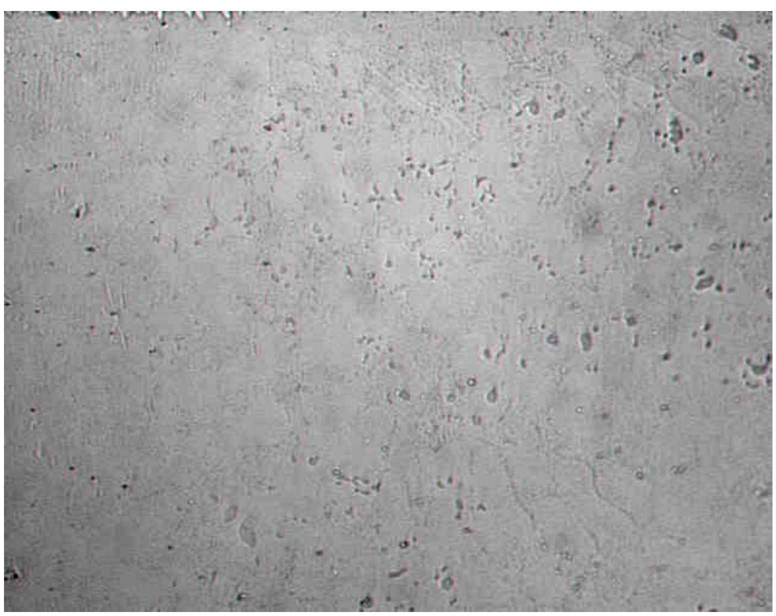

Fig. Xx –1.27° C/sec cooling reflowed in air environment, 50x magnification, and polished condition.

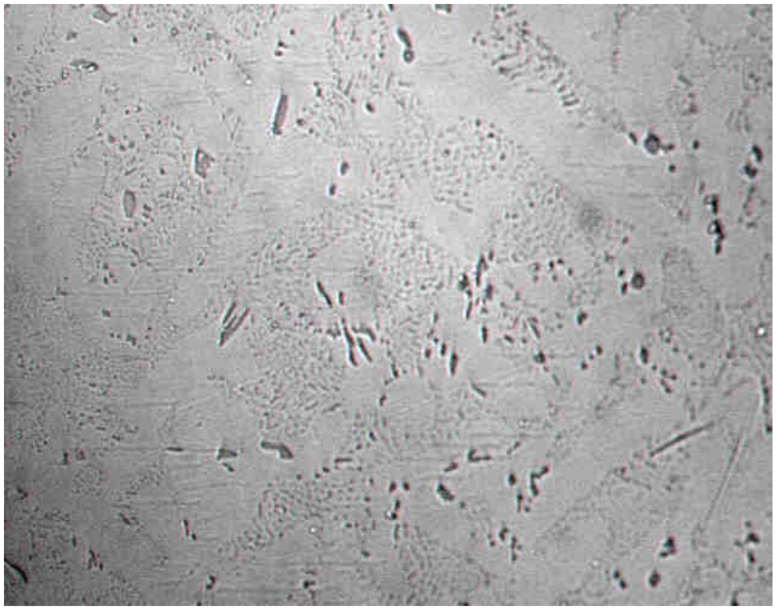

Fig. Xx –1.27° C/sec cooling reflowed in nitrogen environment, 50x magnification, and polished condition.

Conclusion
The following conclusions were determined from the experiment and analysis of the samples.

- Aggressive cooling slopes resulted in smaller, diffused Sn rich dendrites within a finer mix of eutectic grain structures forms. This resulted in a more uniform mix of the material as it solidified.
- Mild to gradual cooling slopes resulted in longer eutectic grain structures within longer and layered Sn rich forms.
- There was no significant visual affect between samples reflowed in an air environment vs a nitrogen environment in terms of grain structure.
- Shear strength testing is required in order determine the affects of cooling slopes on solder joint strength.

Lead Free Reflow Recommendations
For lead free reflow cooling it is recommended that an aggressive cooling slope be utilized for the best diffusion of the material and fine eutectic grain structures. When using an aggressive cooling slope, the component manufacture recommendations for maximum cooling and heating slopes should be referenced in order not to cause damage. Although no significant advantage of the solder joint occurred, using nitrogen in the reflow process will assist in spreading of the material.

References

1. **Shiloh, P. John, Malboeuf, John. "How to Profile a PCB". Surface Mount Technology (SMT), February, 2000.**
2. **Ochoa, F. Williams, J.J. Chawla, N. "Effect of Cooling Rate on the Microstructure and Mechanical Behavior of Sn-3.5Ag Solder". JOM (April 2003) submitted. http://www.pbfree.com/pdf/university_research/jom_final_nc.pdf**
3. **Manko, H. Howard. "Soldering Handbook for Printed Circuits and Surface Mounting" 2nd ed. New York: Chapman & Hall, 1995), pg 190-192**
4. **Rhee, H. Subramanian, K.N. Lee, A. Lee J.G. "Mechanical Characterization of Sn-3.5Ag Solder Joints at Various Temperatures". Soldering & Surface Mount Technology, Volume 15 Number 3 2003, pgs. 21-26. http://www.emeraldinsight.com/0954-0911.htm**
5. **Dong, Ross, and Schwarz. "N2 Inerting for Reflow of Lead-free Solders". Advanced Packaging, Novevember 2003, pgs. 29-31.**