

Addressing Low-Temperature Rework Concerns

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ABSTRACT

Implementation of low-temperature solders has been a subject of considerable interest for many consumer electronics manufacturers. Low-temperature solders represent a significant material and process cost advantage over traditional silver-bearing and low-silver alloys. Bismuth-containing alloys enable low-melting temperatures; therefore, if the mission profile of an assembly tolerates the limitations of bismuth-containing low-temperature solders, implementation is favorable.

An overlooked application in implementing low-temperature alloys is rework. The inherent brittleness of bismuth inhibits the manufacturing of fluxed cored wire. An approach to overcome this limitation is to use a high-bismuth solid wire solder with an external flux. This approach introduces challenges associated with implementing new materials and training operators on new rework techniques. Another approach is to use traditional tin (Sn)/ silver (Ag)/ copper (Cu) (SAC) flux cored wire solder to rework low-temperature solder joints. Rework conditions differ from other reflow processes given considerable process variability due to operator input.

This paper will detail the material properties and rework considerations of using a eutectic tin/bismuth (Sn/Bi) solid wire and SAC305 (Sn96.5/Ag3/Cu0.5) flux cored wire in a rework setting. Solder joint quality of Sn/Bi combined with SAC305, in both through-hole and surface mount applications, will be assessed along with:

a. Diffusion zone of SAC305 and Sn/Bi

b. Shear strength of the resulting solder joint versus, SAC/SAC, SAC/Sn-Bi, Sn-Bi/Sn-Bi.

The goal of this study is to provide the end-user guidance on rework materials and techniques that can be successfully implemented during the implementation of low-temperature solders and to identify any trouble spots.

INTRODUCTION

Low-temperature (LT), high-bismuth solders are being carefully considered to replace SAC305 for several reasons including minimizing component warpage, reducing energy consumption and lowering the cost of solder, substrate, plastics, and other materials. Bismuth is strong, but also brittle and has different mechanical properties than the SAC alloys they replace [1]. Despite these drawbacks, consumer electronics that are not subjected to high thermal or mechanical stress may be candidates for low-temperature materials.

Most published studies have overlooked one important consideration when implementing low-temperature alloys: rework and post-assembly attachment processes. This paper will review the issues associated with using low-temperature alloys in the benchtop setting and how these alloys can be implemented or combined with existing processes and materials.

DISCUSSION

SAC305 is the PCB assembly standard since lead (Pb) was banned from electronic solders for environmental concerns in 2008. This change forced the implementation of new

equipment and materials due to the higher melting temperature of SAC305 versus the tin/lead materials it replaced. One of the main benefits of SAC305 was its compatibility with tin/lead solders. Other elements were considered as part of the Sn/Pb replacement, such as indium and bismuth. Both were attractive as they lower the melting temperature of SAC alloys. However, indium was eliminated for supply and cost issues and bismuth was eliminated because when combined with Sn/Pb, a ternary alloy with a melting temperature of 97°C is formed causing an unacceptable loss of reliability.

Regulations limiting the use of Pb in electronics have effectively removed it from the industry's material supply chain, reinvigorating the interest in bismuth-bearing solder alloys. Given the advantages of a low-melting point alloy, solder manufacturers stay motivated to develop commercially viable products for solder paste, solid alloy, and flux cored wire, but this is not without its challenges.

The physical properties of elemental bismuth are unusual. It has one of lowest thermal and electrical conductivity values of all metals, it is denser as a liquid than a solid, it expands on freezing, and is the most naturally diamagnetic element on the periodic table. Aside from these interesting factors, bismuth's brittleness is what has the greatest impact on its soldering performance. An alloy with a bismuth percentage above 6% will begin to lose ductility/become more brittle. Brittleness should not be confused with loss of strength; bismuth alloys are strong, but brittle.

Sn42/Bi57/Ag1 is eutectic at 138°C, meaning the liquidus to solidus are coincidental, there is no plastic state. Adding elements such as silver and indium (In) can improve strength or ductility to high-bismuth alloys but they will still behave like high-bismuth alloys – strong and brittle. This not only creates issues for PCB assemblers, but it also has a profound impact on the manufacturability of Sn/Bi wire solders. Manufacturing wire solder relies on the ductility of the alloy to allow it to be shaped and formed. When producing flux cored wire, these traits are vital. Flux cored wire is simply a metal tube formed around a die via an extrusion process, subsequently drawn through progressively finer dies. This thin metal tube is prone to cracking and breaking as the equipment relies on a continuous wire to operate correctly. Extrusion presses must be specially outfitted to run high-bismuth wires and run at significantly slower speeds compared to typical SAC alloys. These factors add considerable cost to manufacturing.

Sn/Bi can recrystallize at room temperature therefore this once ductile material can become brittle over time resulting in flux cored wire solder being prone to breaking as it is unspooled. This makes low-temperature alloys poorly suited for fine diameters or robotic soldering applications.

Finally, Sn/Bi alloys are slower wetting alloys compared to SAC therefore require more aggressive fluxes to promote

spread and flow to facilitate barrel fill and sufficient wetting [2].

These realities leave assemblers using low-temperature solders with three practical options when reworking assemblies: implement high-bismuth low-temperature flux cored wire solder with the material, cost, and availability issues, implement solid high-bismuth wire solder with an external flux, or use SAC flux cored wire in combination with the low-temperature alloy used during the assembly process.

The study will evaluate these three options and provide feedback on the performance characteristics during processing and compare the resulting solder joints using the IPC610 standard, cross-section evaluation and shear strength testing.

EXPERIMENTAL METHODOLOGY

Three rework conditions were followed to compare the performance of high-Bi solders to a SAC305 baseline during rework and post-assembly processes. Condition 1 uses Sn42/Bi57/Ag1 paste and SAC305 flux cored wire. Condition 2 uses Sn42/Bi57/Ag1 paste but is different from condition 1 in that solid Sn42/Bi57/Ag1 wire and external flux is used. Finally, condition 3 employs SAC305 paste and SAC305 flux cored wire for rework. All flux mediums in use are no clean thus, cleaning was not performed.

IPC610-J-STD-001-REVF/G-LF Solder Training Kit, as seen in Figure 1, was used in this study because of its combination of SMT and PTH component types. The assortment of components enables the use of a combination of post-assembly soldering techniques. The following components were tested in this study:

X-section

R1, U1, CR4, and U3.

Shear testing

R3, R4, C3, C4, CR3, CR4, R5, and R6.

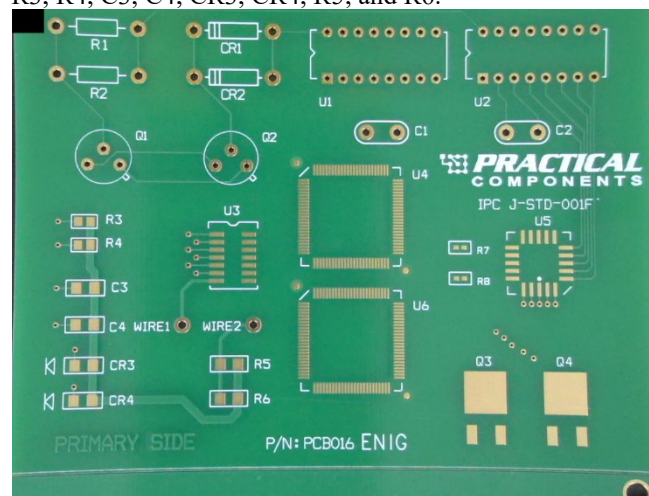


Figure 1. IPC016-IPC J-STD-001-REV F/G-LF Solder Training Kit

Phase 1 assembly took place in AIM Solder's Technical Applications laboratory in Juarez, Mexico. A 5 mil, laser cut

stencil using PHD stainless steel, mounted at standard tension (~34 N/cm) with apertures designed to promote defects was employed. The stencil design included engineered defects such as BTC apertures combined into one to form for solder bridging pads, as indicated by the blue arrows in Figure 2. Also one of each chip component outlined in red, per Figure 2, was printed using the inverted home-plate design while the second identical component was printed 1:1 with the pad to promote solder balling.

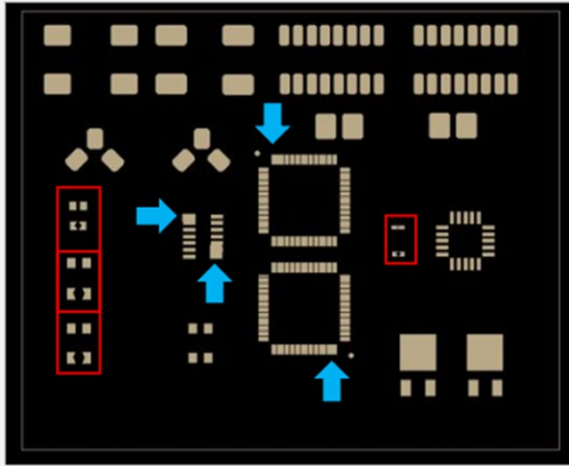


Figure 2. Stencil designed to promote defects

Solder paste was printed using a DEK HORIZON 3AA. The pin-in-paste (PiP) method was used for PTH components. The deposits were inspected for consistent paste volume using a PARMi SIGMA X SPI. After printing, the board was populated using an I-PULSE M10 pick and place machine and the PTH components were inserted manually. The boards were then reflowed with their respective profiles using a HELLER INDUSTRIES, Model: 1936 MK5. A total of eighteen boards were assembled to allow for the experimentation and assessment of various rework techniques. Twelve boards were assembled with AIM no clean Sn42/Bi57/Ag1 paste following the reflow profile in Figure 3 with a peak temperature of 170°C.

Table 1. List of materials and peak reflow temperatures used for low-temperature solder assemblies

Board #	Paste	Peak Reflow (°C)	Rework Wire	Flux
1	Low Temp	170	SAC	cored
2	Low Temp	170	SAC	cored
3	Low Temp	170	SAC	cored
4	Low Temp	170	SAC	cored
5	Low Temp	170	SAC	cored
6	Low Temp	170	Low Temp	liq/gel
7	Low Temp	170	Low Temp	liq/gel
8	Low Temp	170	Low Temp	liq/gel
9	Low Temp	170	Low Temp	liq/gel
10	Low Temp	170	Low Temp	liq/gel

11	Low Temp	170	Low Temp	liq/gel
12	Low Temp	170	SAC	cored

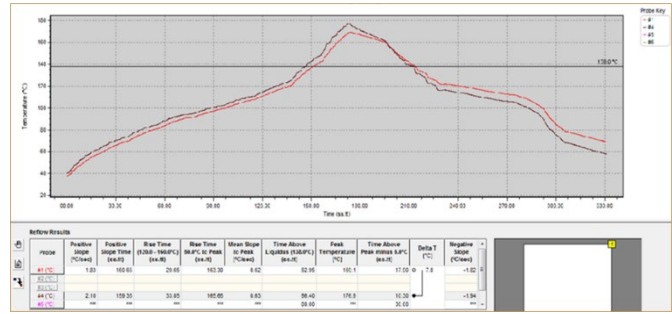


Figure 3. 170°C Peak reflow

Six boards, listed in Table 2, were assembled using AIM no clean SAC305 paste following the reflow profile in Figure 4 with the peak reflow temperature of 246°C.

Table 2. List of materials and peak reflow temperatures used for SAC solder assemblies

Board #	Paste	Peak Reflow(°C)	Rework Wire	Flux
1	SAC	246	SAC	cored
2	SAC	246	SAC	cored
3	SAC	246	SAC	cored
4	SAC	246	SAC	cored
5	SAC	246	SAC	cored
6	SAC	246	SAC	cored

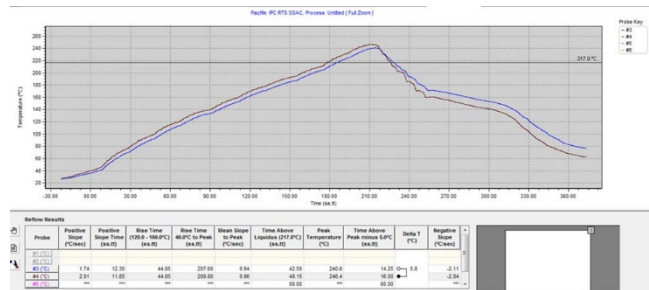


Figure 4. 246°C Peak reflow

After assembly, the next phase was simulating various rework/post-assembly processing techniques under each soldering condition. This was conducted at EPTAC Corporation, in Manchester, New Hampshire.

Rework was performed with a soldering iron (Figure 5) with a chisel tip (Figure 6) set to 630°F/330°C. AIM no clean flux cored SAC305 wire was used to rework twelve total boards: six of the twelve assemblies using Sn42/Bi57/Ag1 paste, per condition 1, and six assemblies using SAC305 paste, per condition 3. The remaining six boards assembled using Sn42/Bi57/Ag1 paste were reworked using solid Sn42/Bi57/Ag1 wire combined with AIM no clean liquid flux

for PTH components and AIM no clean gel flux for SMT components.



Figure 5. Soldering station with soldering iron

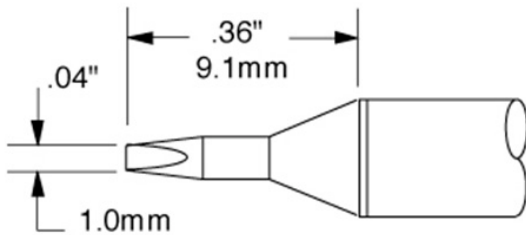


Figure 6. Chisel tip

The second part of this phase comprised of reproducing the rework techniques applied and capturing them on video. This was completed in Essex, England by Bob Willis, an independent consultant.

Rework Techniques and Tooling

None of the components used in rework were prepped or pre-tinned prior to being assembled to the board.

PTH

The PTH components were removed by cutting the component leads, applying liquid flux to the remaining solder joints, and removing the components with heated tweezers. The through-hole via were cleaned with the copper braid. Four axial components, two radial caps and one IC was removed from each board.

SMT

The surface mount components were removed with heated tweezers (Figure 7). The pads were prepped for new components by applying no clean liquid flux and solder braid to remove excess solder. No clean rework gel flux was then applied, and a small amount of solder was applied to prepare for the installation of new components.



Figure 7. Hot Tweezers were used to remove SMT components

Once the pad terminations were prepared and fluxed, the components were placed onto the pads, the solder was reflowed using hot air, and the components were slid onto the molten solder alloy. The process was repeated on the opposite side.

The intentionally designed SMT defects such as bridges on the gull wing components, were reworked by applying gel flux and copper braid, heated with the soldering iron, to wick the solder away. The joints were reflowed with the no clean gel and the low melt alloy was reapplied to verify the joint met the requirements of the J-STD-001 document.

ANALYSIS METHODOLOGY

Cross-section analysis was conducted on one PTH and two SMT components per soldering condition: R1, U1, and CR4, respectively. This was done to investigate the impact of the various rework techniques and soldering condition on intermetallic compound (IMC) formation.

Mechanical shear testing was conducted on SMT components R3, R4, C3, C4, CR3, CR4, R5, and R6 at a constant speed of 0.1mm/s and a shear height of 0.15mm.

RESULTS

Rework Observations

All the surface mount components were prepared using no clean gel flux and PTH components with no clean liquid flux. It was noted that solid low-temperature solder did not wet the solder iron tip as well as the flux cored SAC305 wire which was not surprising.

The solid Sn/Bi wire worked well with the addition of the application of external flux. The solder joints were visually inspected and met the requirements of J-STD-001. When using solid low-temperature wire, the solder iron tip remained tinned and functional with no degradation of the tip tinning.

When using SAC305 flux cored wire, soldering the smaller size surface mount components proved challenging due to the large wire diameter. Although the joints appeared to have excess solder, they met the wetting requirements according to J-STD-001.

Solder Joint Analysis

Cross-Section Analysis

The cross-section analysis showed typical IMC formation for all the reworked joints. Figures 8-10 display the typical IMC formation for each soldering condition.

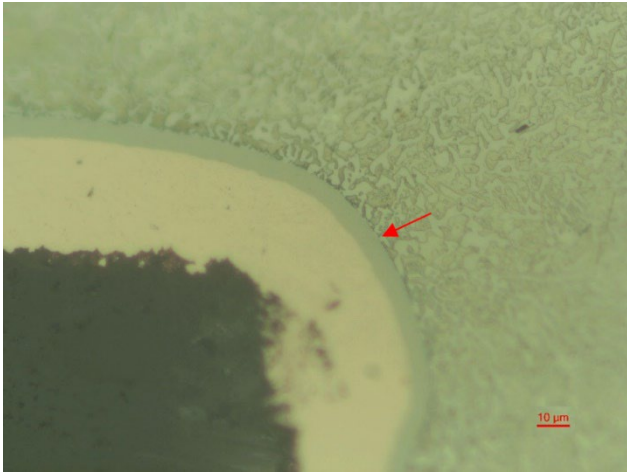


Figure 8. Sn42/Bi57/Ag1 paste reworked with solid Sn42/Bi57/Ag1 wire and external flux

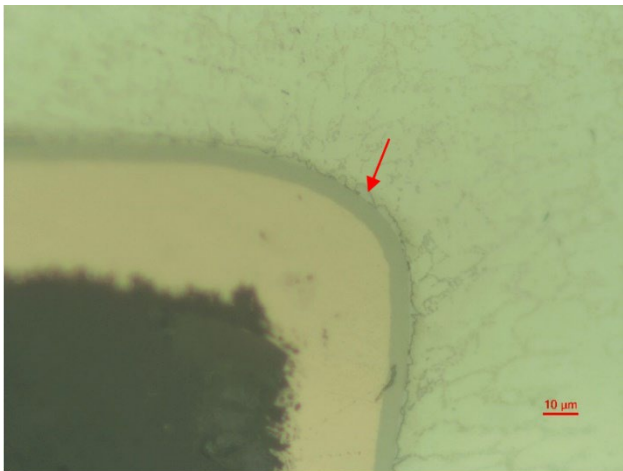


Figure 9. Sn42/Bi57/Ag1 paste reworked with SAC flux cored wire

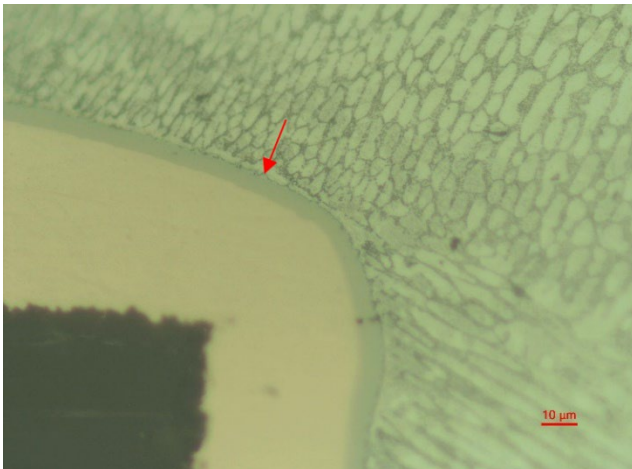


Figure 10. SAC paste reworked with SAC flux cored wire

The SMT components (CR4 and U3) are well formed, showing good wetting on pads of PCB and terminations of components.

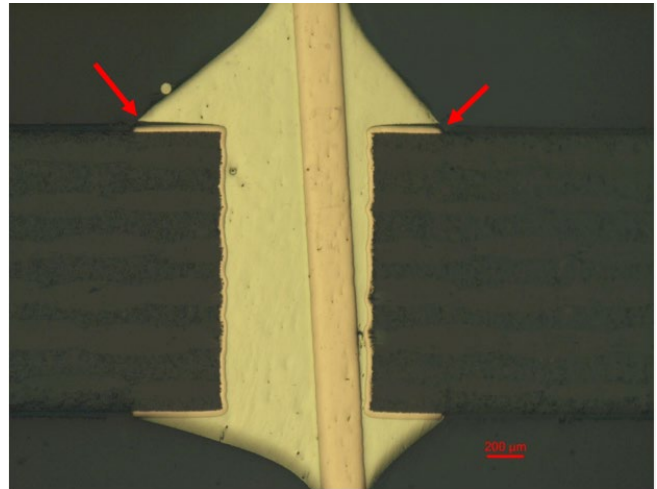


Figure 11. Fillet lift on Sn42/Bi57/Ag1 paste reworked with SAC flux cored wire

Almost all the PTH joints have 100%-barrel fill, however, fillet lifting phenomena on topsides are observed at R1 of board #2 and U1 of board #1 in SAC/LT case, as seen in Figure 11. Fillet lift is a common occurrence when using high-bismuth alloys and is NOT a defect per IPC610. It was noted that intermetallic layers for high Bi solders are thinner than SAC alloys.

In conclusion, rework has been successfully performed, with no observed defects under all test conditions. All solder joints were acceptable per IPC-610 inspection criteria.

Shear Testing

Shear test results for components C3, C4, CR3, CR4, R3, R4, R5 and R6 are shown in Figures 12-15.

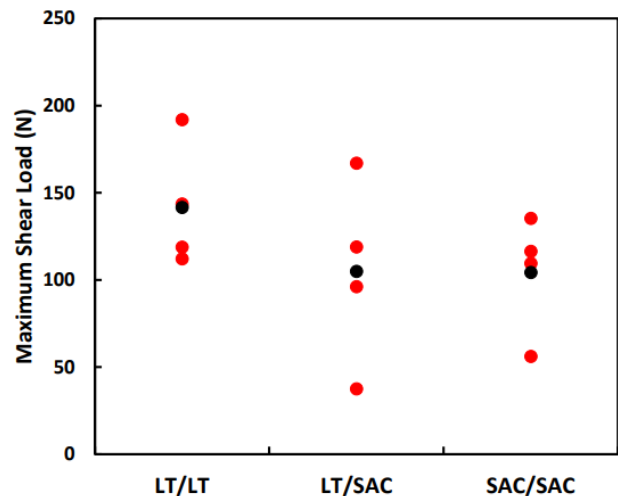


Figure 12. Shear force Vs extension relationship for C3 and C4 components

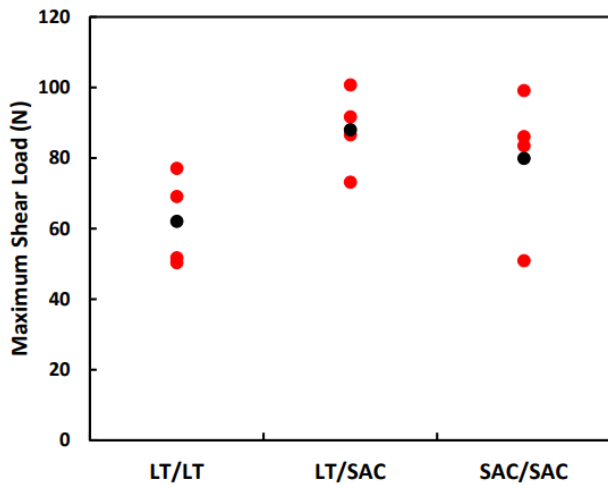


Figure 13. Shear force Vs extension relationship for CR3 and CR4 components

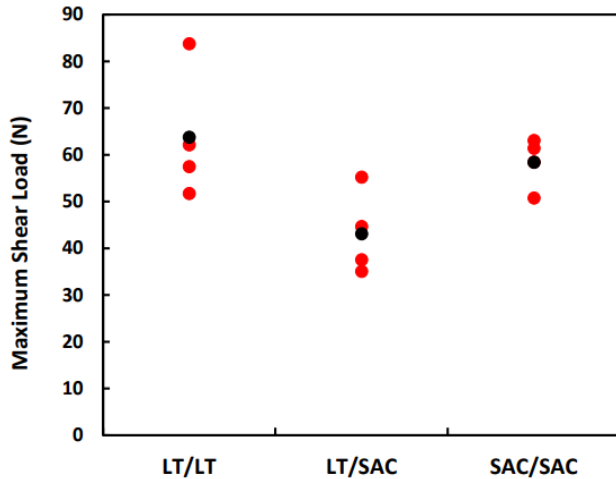


Figure 14. Shear force Vs extension relationship for R3 and R4 components

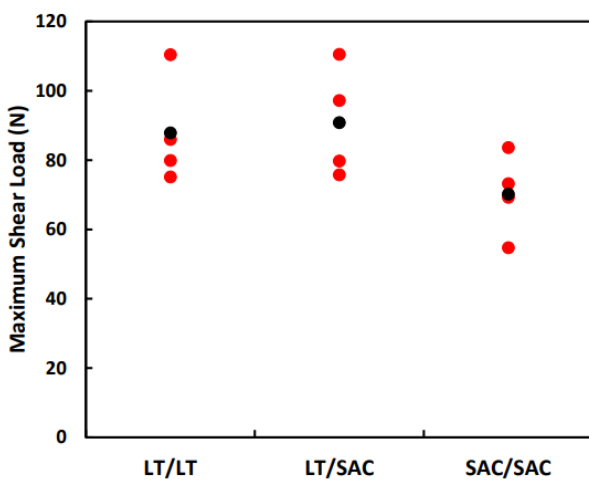


Figure 15. Shear force Vs extension relationship for R5 and R6 components

Each soldering condition performed comparably during shear testing with slight variation per component. The variation seen within a single soldering condition, no matter the

component, can be attributed to the variable nature of rework. Rework is a manual operation, and the quality of a reworked solder joint is highly influenced by operator input. Shear testing did not show a clear outlier in mechanical performance over the three soldering conditions.

Figures 16-18 display the typical shear force vs extension relationship per soldering condition. The high-bismuth (LT reworked with LT) curve seen in Figure 16 is sharp, indicating that the alloy can withstand load (N) but breaks abruptly due to its brittle properties.

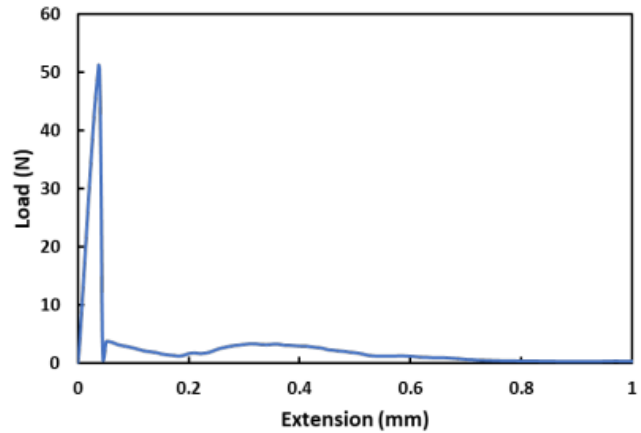


Figure 16. Typical shear force Vs extension relationship for component printed with LT paste reworked with LT wire and external flux

Figure 17 shows the curve of the LT paste reworked with SAC flux cored wire, displaying a less sharp curve and greater extension (mm), indicating it is more ductile than LT paste reworked with LT wire and external flux (Figure 16).

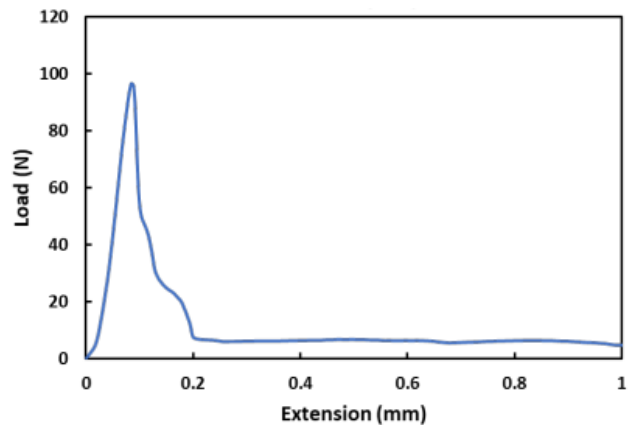


Figure 17. Typical shear force Vs extension relationship for component printed with LT paste reworked with SAC flux cored wire

Finally, Figure 18 illustrates how the SAC paste reworked with SAC flux cored wire extends the greatest but withstands less load (N) before extension compared to the LT paste reworked with SAC flux cored wire (Figure 17).

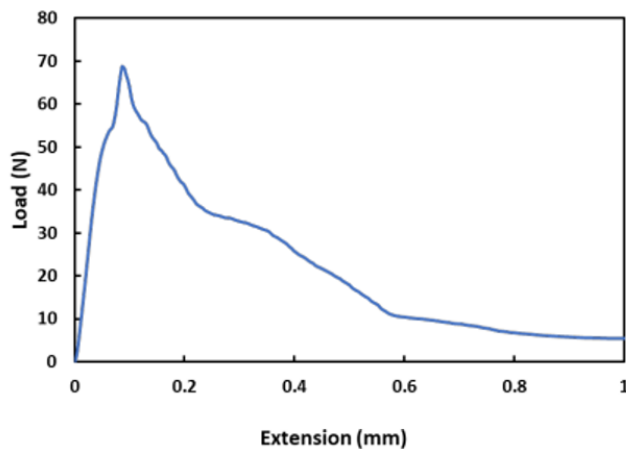


Figure 18. Typical shear force Vs extension relationship for component printed with SAC paste reworked with SAC flux cored wire

CONCLUSION

Low-temperature alloys used in SMT and PTH processes can be successfully reworked using low-melting temperature solid wire and external flux as well as with flux cored SAC305 wire solder. The low-temperature solder behaves differently in process than the SAC equivalent but was not an obstacle in creating quality solder joints. Solid wire with external flux will require qualification of an appropriate flux for the application requirements. As with any externally applied flux, residue, and reliability characteristics due to processing techniques must be considered.

The resulting solder joints met IPC Class 1, 2, 3 solder joint criteria. The shear test results were inconsistent due to the variable nature of rework, but trends are visible. SAC solder joints were more ductile than Bi bearing counterparts. This is not unexpected. SAC+Sn/Bi solder joints shear results reflected the properties of the combined alloys. The operator in this study is an IPC hand soldering certification instructor with decades of experience. Even with a highly qualified operator, results are variable. This highlights the importance of operator training in implementation of low-temperature rework.

When using SAC305 flux cored wire solder, the process was like existing SAC/SAC rework processes. No special considerations were noted other than to considering finer wire diameters when reworking small components.

Low-temperature flux cored wire solder was NOT included in this study due to the prohibitive cost to the end-user and limited availability.

FUTURE WORK

Based on the outcomes of this study, more testing has been scheduled. The effect of low-temperature alloys on soldering iron tip life and equipment will be evaluated. In theory, lower operating tip temperature will extend solder tip life, offering another cost saving opportunity for low-temperature implementation. In addition, low-temperature alloy flux

residue was noticeably darker than the SAC alloy residue. Analysis indicated the presence of bismuth oxide which is an aesthetic concern. Future testing will include the ease of cleaning these dark residues in both the assembly and rework setting.

ACKNOWLEDGEMENTS

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