Direct Aluminum Soldering Paste

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ABSTRACT

Soldering aluminum to copper provides an excellent thermal and electrical connection pathway for this increasingly important joining requirement involving copper-aluminum heat sinks. Typically, aluminum soldering is accomplished by plating over the aluminum to make that surface solderable. The development of a direct aluminum soldering paste eliminates the costly plating operation.

The stable direct aluminum soldering paste provides for a soldering option that will work via induction, oven reflow, hot plate, or soldering iron techniques. The paste consists of a special flux medium and lead-free solder alloy. Evaluation of the solderpaste was conducted by several methods. Solderability testing compared the paste on a variety of aluminum alloys. Soldering joint cross-sectioning followed by scanning electron analysis proved the viability of the solder joints. Tensile strength testing of the solder joints measured the strength of the copper to aluminum and aluminum to aluminum solder joints.

INTRODUCTION

The direct aluminum soldering paste was developed for applications that need aluminum soldering with solder paste application. Solder paste soldering of plated aluminum is currently done by the heat sink industry. By “direct aluminum soldering”, the concept is to perform the soldering to aluminum surfaces without pre-plating of the aluminum parts before soldering, an expensive process. The paste utilizes a water-soluble chemistry so cleaning involves simply rinsing in hot water. One of the challenges in developing this solder paste was to make it stable over time and eliminate the problems of paste separation. Once these problems were overcome, evaluation of the viability of this new product was required.

Since various aluminum alloys have widely varying degrees of solderability[1], a number of aluminum alloys that are commonly used in applications that might need a soldered connection were evaluated. Aluminum alloy 1145 was tested since it is very similar to construction materials used for heat sinks. For many aluminum constructions, a popular alloy is 3003 aluminum. 1350 alloy aluminum was tested because of its popularity as a replacement for copper in electrical wire. The 6061 alloy aluminum was tested as it is commonly used owing to its excellent extrusion and machining properties. Finally, copper was also evaluated as a base line; since many of the applications for heat sink soldering, LED lighting, and electronic component connections involve aluminum to copper connections.

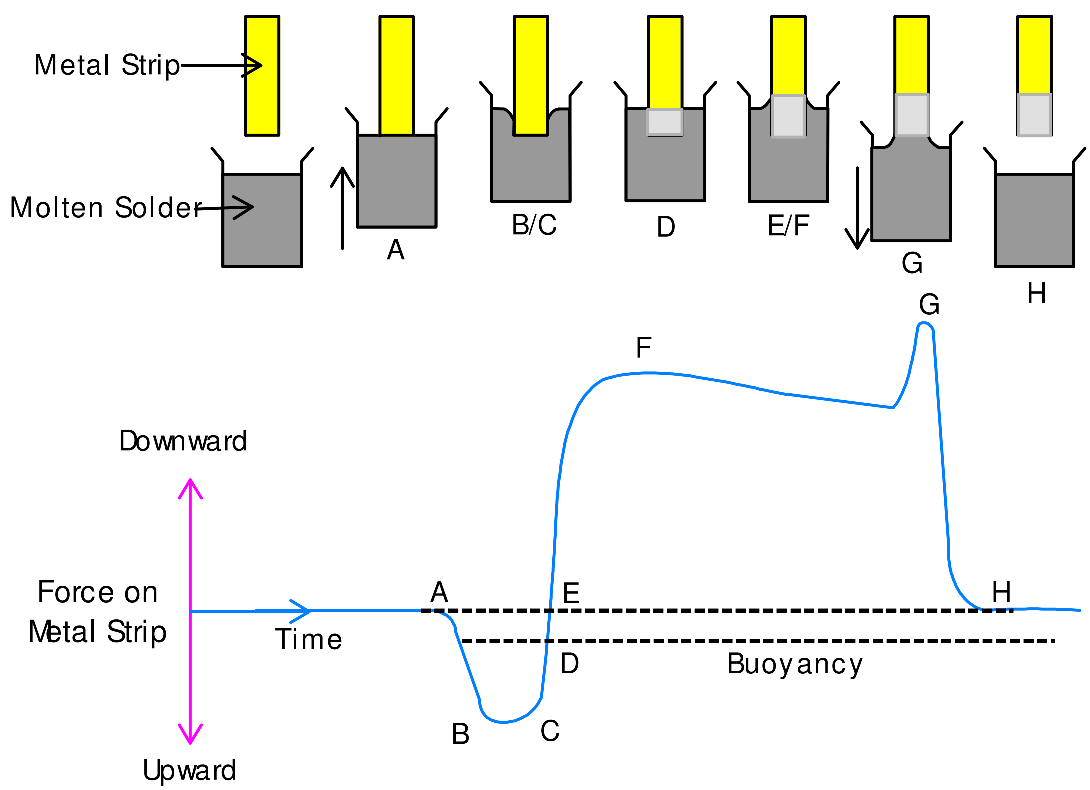
The choice of solder alloy 96.5/3.5 tin-silver for development of the paste for this application was made based on previous studies for direct aluminum soldering[2] which detailed the importance of making the proper solder alloy to aluminum intermetallic bond. This is particularly important when it comes to developing materials to make the thermal transfer bonding for a device like a heat sink[3].

SOLDERABILITY TESTING

The solderability tester measures the interfacial force between molten solder and the specimen being soldered; in essence, measuring the ability of the solder to flow on a surface. A common definition of solderability is "the ability of a metal to be wetted by molten solder". The solderability test is unique in that it permits the simultaneous evaluation of base metal, solder, and flux to determine the effect of these factors in the soldering process. Two of the factors are held constant while the third is the variable. An earlier solderability test compared various aluminum soldering fluxes to different aluminum alloys and solders[4].

In this test one of the unique qualities of the solderability tester is used: the ability of a metal to be wetted by molten solder. The alloy used is solder from the solder pot of the solderability tester but the flux is the solder paste. In measuring the solderability of the solder paste on the base metal, the measurement of the overall effectiveness of the solder paste is measured. The soldering is done with the same alloy for the solder paste and the molten solder of the solderability tester so no cross contamination occurs and one is still measuring the effectiveness of the flux used to make up the solder paste.

The solder pot is raised to immerse the specimen to a preset depth below the solder for a set period of time. The load cell measures the weight change as solder draws up the test specimen. The weight difference is converted to wetting force by an on-line computer analysis. The solder pot then is lowered at the end of the immersion cycle, pulling the specimen out of the solder. To evaluate the results, the height of the curve within the immersion time of the solderability test dip is measured in terms of wetting force. The wetting force is a measure of the extent of solder flow. Greater solder flow will result in better soldering.



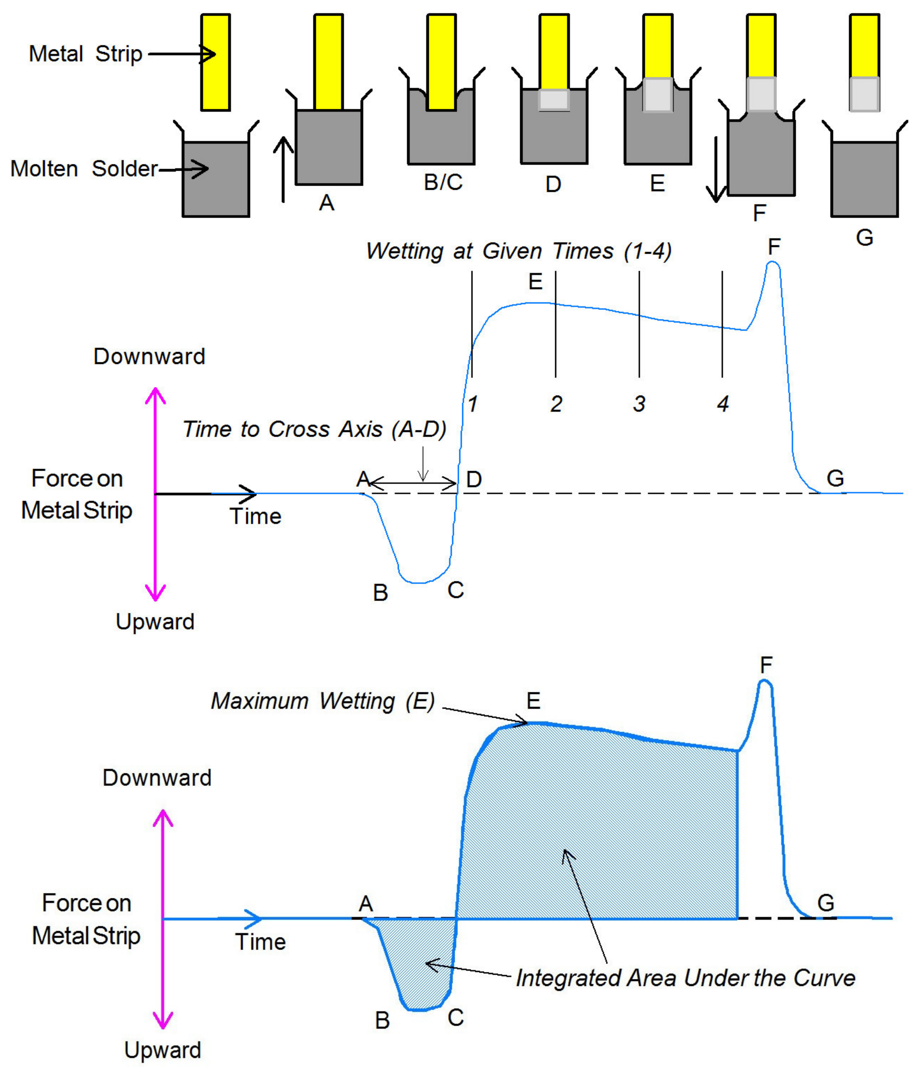
SOLDERABILITY TEST TERMS

Time to Cross Axis (**TCA**) - Time, in seconds, needed to achieve positive solder wetting. This is the measure of how fast the solder will start to spread on a surface.

Solder Wetting (in µN/mm) at given Times - Wetting force expressed in micronewtons / millimeter (µN/mm) at the time indicated in the solderability curve.

Maximum Wetting (**MW**) - Maximum force; expressed in micronewtons/ millimeter (µN/mm), in the positive solder wetting region of the solderability curve. This is a measure of how far the solder will spread on a surface.

Integrated Area under the Curve (**IA**) – The area between the curve and the x-axis during the entire immersion cycle. The area is recorded in units of micronewtons/millimeter-seconds (µN/mm-sec). This is a measure, which combines the effects of both maximum wetting and time to cross axis to give a single performance value.



SOLDERABILITY TEST MATERIAL

- ***Solder Paste:***
  - Superior AL26-33-75: Direct aluminum soldering paste based on 96.5/3.5 tin-silver
- ***Solder:***
  - 96.5/3.5 Tin-Silver: One of the oldest and most reliable lead-free alloys with a long history of soldering electrical connections. Eutectic alloy melting point 221°C.
- ***Base Metals:***
  - 1145 Aluminum: Highly solderable aluminum alloy used in making soldered parts like heat sink fins.
  - 3003 Aluminum: Manganese-containing aluminum used for general sheet metal work, drawn parts, and storage.
  - 1350 Aluminum: Aluminum alloy with particular electrical passing properties, widely used for electrical wire.
  - 6061 Aluminum: Low cost aluminum alloy with excellent extrusion and machining properties.
  - C14530 Copper: Tin-tellurium based copper alloy used for fin stock.

SOLDERABILITY EQUIPMENT

- Meniscograph Solderability Tester
- Bascom-Turner Model 4120T Digital Chart Recorder / Computer

SOLDERABILITY TEST PROCEDURE [5, 6]

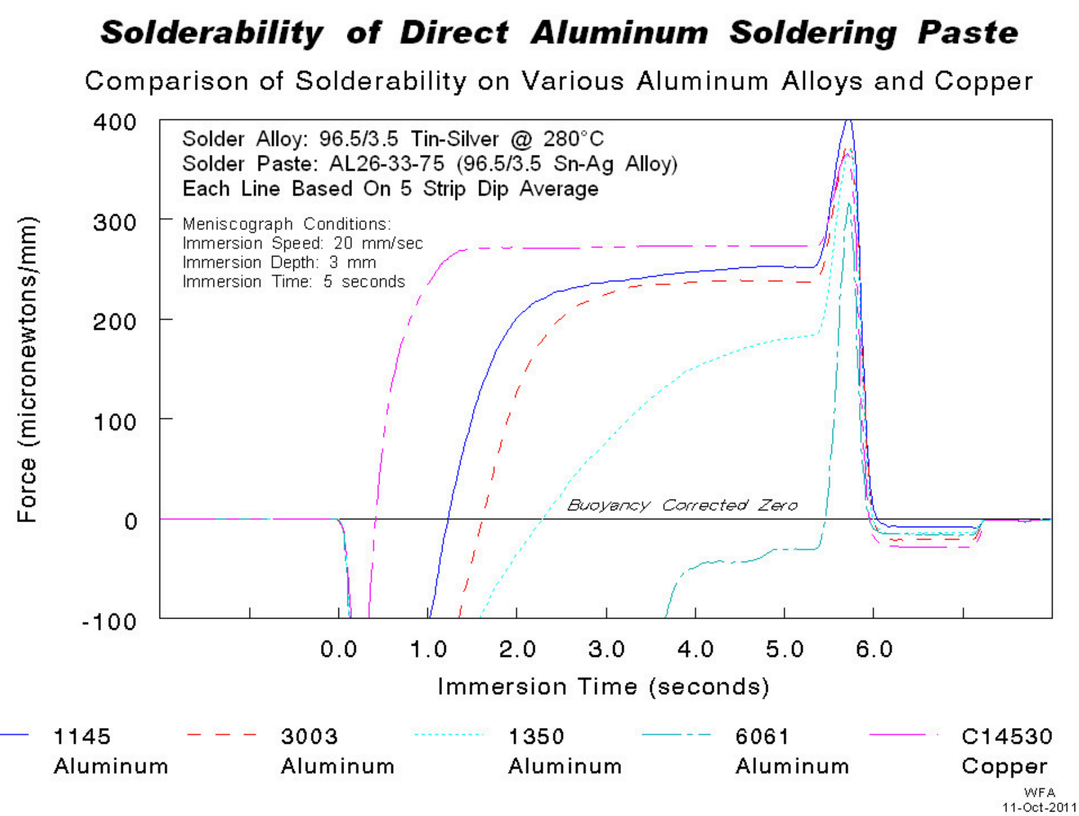
1. Stabilize the solderability tester pot at the desired temperature to within ± 1°C. Use the following parameters for the solderability tester:
   - Pot Temperature : 280°C
   - Immersion Speed : 20 mm/sec
   - Immersion Depth : 2 mm
   - Immersion Time : 5 seconds
2. Attach the test part to solderability tester holder. Coat both sides of the test part by hand printing paste to a depth of 2 mm with a thickness of 1.016 mm (0.040 inches).
3. Put the holder on the solderability tester's load cell connection above the molten solder. Wipe the solder surface clean of any dross. Activate the solderability tester and observe the dipped sample and the curve created by the chart recorder. Save the curve to the chart recorder disk drive.
4. Repeat steps 2-3 five times.
5. Change the base metal alloy and repeat steps 2-4 until all alloys have been tested.
6. Transfer the data to the computer to get numeric and graphic information.

TEST RESULTS

96.5/3.5 Tin-Silver @ 280℃ with Superior AL26-33-75 Solder Paste

Alloy Tested	TCA	Solder Wetting (in µN/mm) at given Times 0.70s	1.00s	2.00s	3.00s	4.00s	5.00s
1145 Aluminum	1.22	-202	-113	202	237	248	252
3003 Aluminum	1.62	-209	-206	127	225	237	238
1350 Aluminum	2.28	-209	-209	-35	77	152	180
6061 Aluminum	4.14	-209	-209	-172	-158	-49	-31
C14530 Copper	0.42	174	234	272	272	273	273

Alloy Tested	MW	IA @ 5.00s
1145 Aluminum	253	635
3003 Aluminum	239	443
1350 Aluminum	180	7
6061 Aluminum	-3	-692
C14530 Copper	274	1140



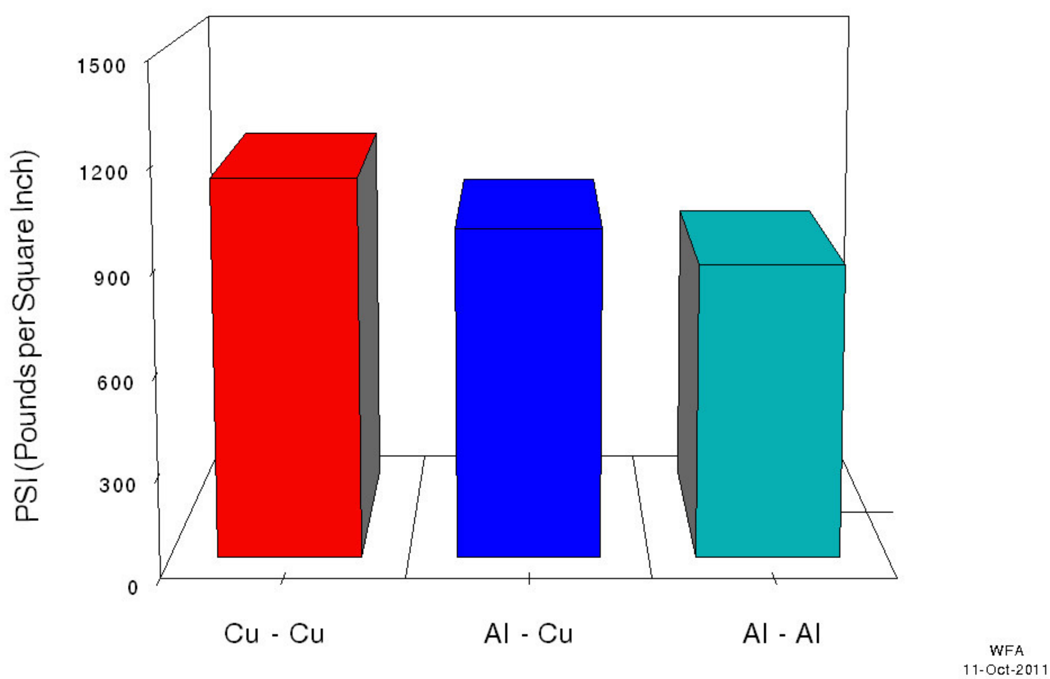
TENSILE STRENGTH TESTING

To measure the overall strength of the solder bonds created a simple tensile strength test was done. A lap joint was created between copper-copper, copper-aluminum, and aluminum-aluminum parts using the direct aluminum solder paste as the connecting media.

The lap joints were formed by placing the paste between two parts joined to make a 1 inch lap joint with a 0.030 mm distance between the two parts. The parts were heated on a hot plate to make the solder joint then cooled. The joint strength was tested by pulling it apart using a tensile tester.

Combination Tested	Tensile Strength (PSI)
Copper to Copper	1138
Aluminum to Copper	988
Aluminum to Aluminum	882

Tensile Testing of Direct Aluminum Solder Paste



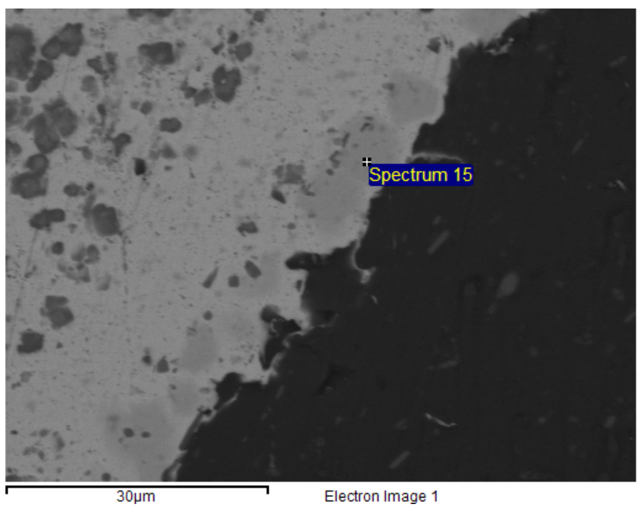
CROSS-SECTION EVALUATION OF SOLDER JOINT

One of the important criteria of the creation of a proper soldering connection between base metal and solder is the formation of the intermetallic bond. Once this bond (the diffusion of solder into the base metal and the diffusion of base metal into the solder) is developed, the completeness of the soldering process can be verified.

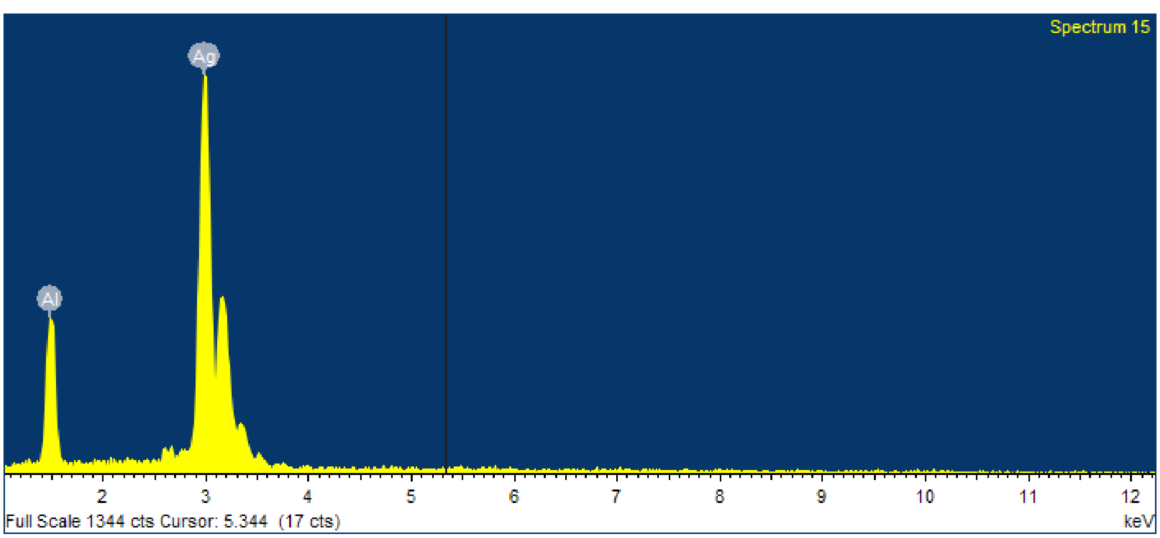
For this evaluation, heat sink parts (1150 aluminum fins and copper bases) were used to create solder to aluminum and solder to copper bonds. The solder paste was used with these parts to reflow with hot plate heating to make the solder bond from heat sink copper base to unplated aluminum fins. The soldered parts were then mounted in epoxy then cross-sectioned and polished. A scanning electron microscope (SEM) was used to evaluate the presence of the intermetallic bond needed for proper aluminum to copper soldering.

SOLDER TO ALUMINUM

When the cross section of the 96.5/3.5 tin-silver solder to aluminum fin connection is examined there is a unique compound formed at the aluminum to solder interface.

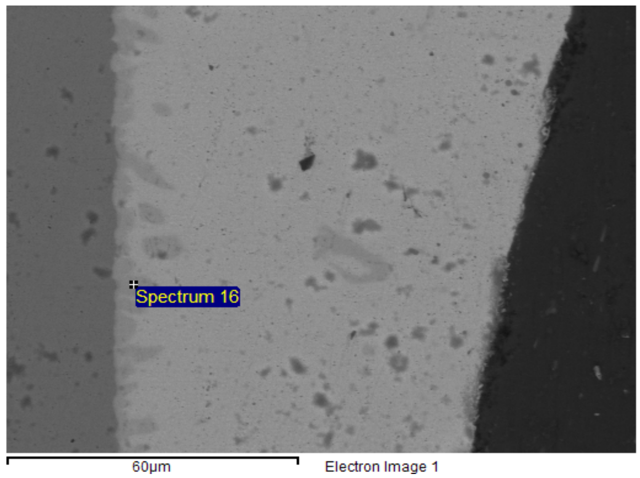


The SEM evaluation of this compound shows that it is a silver-aluminum intermetallic.

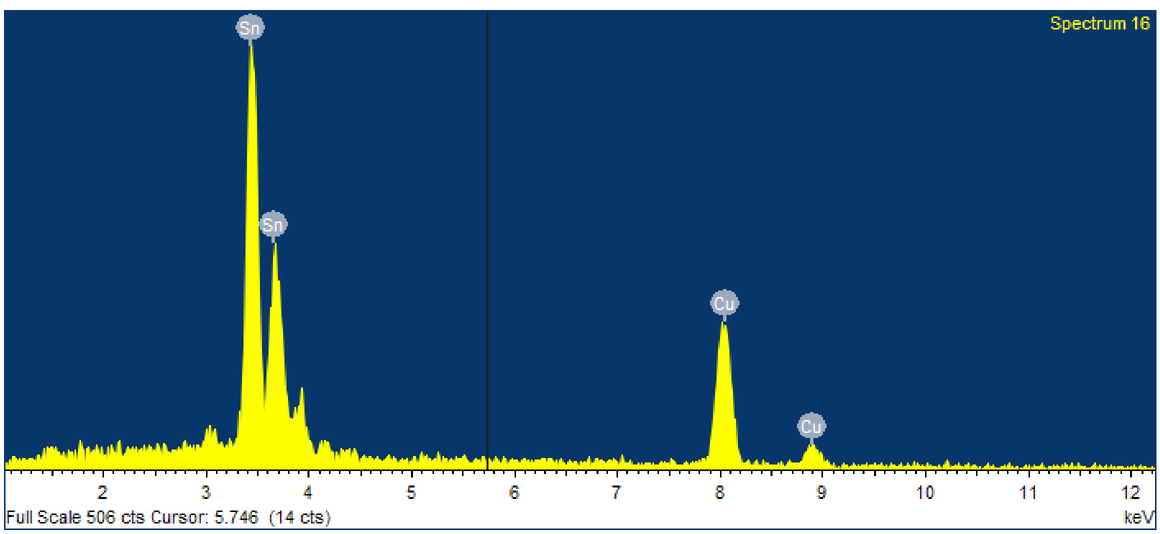


SOLDER TO COPPER

When the cross section of the 96.5/3.5 tin-silver solder to copper base connection is examined there is a unique compound formed at the copper to solder interface.



The SEM evaluation of this compound shows that it is a tin-copper intermetallic.



CONCLUSIONS

From the solderability test, it can be stated that the direct aluminum solder paste will permit easy soldering of 1145 and 3003 aluminum alloys. The paste works best with copper. From these results, soldering of 1145 to copper or 3003 to copper should be effective. Soldering to 1350 alloy aluminum is more difficult but can be accomplished given enough time. Soldering to 6061 alloy aluminum with this solder paste is not recommended.

The solderability test also shows that for aluminum soldering reducing the amount of flux present, since the flux is now a small amount of the total mixture with metal powder and binder, is significant for aluminum soldering. The earlier test comparing various aluminum alloys for soldering[4] showed that even 6061 aluminum could be soldered with a liquid aluminum soldering flux. It could not be soldered when the flux was in a much smaller proportion in a solder paste.

From the solder strength tensile testing it can be seen that copper to copper soldering is the strongest, followed by copper to aluminum soldering. Aluminum to aluminum soldering is less reliable and mirrors reports we have had from users of this product.

The cross-sectioning analysis shows that at the aluminum to solder interface a definite silver-aluminum intermetallic bond was created. At the copper to solder bond, a distinct tin-copper intermetallic bond was created. This confirms the viability of this paste as a product to accomplish copper to aluminum soldering.

FUTURE TESTING

One of the questions resulting from this testing is what effect does choice of solder powder in the paste have on the effectiveness of the soldering mechanism on solders. It is planned to evaluate other viable solders (SAC305, other Tin-Silver, and other Tin-Copper solders) with the same test criteria used in this report. If other solders can be shown to have good solderability, good strength and do create true intermetallic bonds they could be judged to be viable for aluminum alloy soldering in paste form.

One of the products in development at Superior Flux is a low temperature solder paste with an alloy system similar to tin-bismuth that will also permit direct soldering to aluminum without plating the aluminum.

The use of the solderability tester to evaluate the solder paste (as opposed to a liquid flux) opens options for a wide set of future testing in this field and others.

REFERENCES

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[5] GEC Meniscograph MK6B Solderability Tester, Operations Manual, The General Electric Company Research Laboratories, Hirst Research Centre, Wembley, Middlesex, England, 1986.

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AUTHOR

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