

# IPC-SPVC-WP-006

## ROUND ROBIN TESTING AND ANALYSIS

### LEAD-FREE ALLOYS

### TIN, SILVER and COPPER

A WHITE PAPER REPORT by the  
LEAD-FREE TECHNICAL SUBCOMMITTEE of the  
IPC SOLDER PRODUCTS VALUE COUNCIL

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## MISSION STATEMENT

In support of IPC's Mission Statement, IPC solder manufacturers recognize that the PWB and electronics assembly industries, comprised of the entire supply chain, must grow profitably. The Solder Products Value Council Steering Committee's objective is to identify and execute programs designed to enhance the competitive position of solder manufacturers and their customers.

## SOLDER PRODUCTS VALUE COUNCIL MEMBERS

|                     |                             |
|---------------------|-----------------------------|
| AIM                 | Koki Company Ltd.           |
| Cookson Electronics | Nihon Superior Company Ltd. |
| Alpha Metals        | P. Kay Metal Supply Inc.    |
| Amtech              | Qualitek                    |
| Avantec             | Senju Metal Industry        |
| EFD Inc.            | Thai Solder Industry Corp.  |
| Henkel Loctite      |                             |
| Indium Corporation  |                             |
| Kester Northrup     |                             |
| Grumman             |                             |

# IPC SOLDER PRODUCTS VALUE COUNCIL LEAD FREE ALLOY COMPARISON

## Introduction and Statement of Problem

Due to marketing and legislative pressures in Asia and Europe, the electronics industry is moving to adoption of lead free solders. These lead free materials are considered by some to be environmentally preferable to the current lead containing solders that dominate electronics manufacturing.

Although the issue as to whether lead free solders are indeed environmentally preferred compared to lead containing solders is still under debate, market and legislative actions are forcing a change in materials used in electronics assembly.

Accordingly solder material suppliers are being asked to provide the electronics industry with solders that are lead free (per the accepted technical definition of that term) and yet still provide all the needed properties – including ease of assembly and reliability – the electronics industry has come to expect from lead containing solders.

At present there are a large number of materials that have been proposed as replacements for lead containing solder. Primary among these are the Tin/Silver/Copper (SAC) alloys.

There are several variations of the Tin/Silver/Copper alloys that have been suggested as the preferred replacements for Tin Lead solders. Two are of special interest: the Japanese adopted alloy of 96.5% Tin, 3.0% Silver and 0.5% Copper and the North American Electronics Manufacturing Initiative (NEMI) alloy of 95.5% Tin, 3.9% Silver, and 0.6% Copper.

Both of these alloys have undergone significant testing. And both of their sponsors believe that their particular choice is the best candidate for replacement of lead containing solders.

The IPC Solder Products Value Council members are technically capable of providing any alloy requested by their customers. However, provision of a range of materials may not, in the view of the IPC SPVC membership, be the best method of serving the needs of the industry.

The SPVC, as producers of solder alloys, believes it is in the best interests of the industry, from the standpoint of product consistency, quality, and the conservations of natural resources, for a consensus to be reached on a standard alloy for the electronics industry.

## Methodology

In order to determine what material is best suited to be the standard alloy, the IPC SPVC members have reviewed the most likely candidates in the current list of contenders and carefully considered:

- What alloys are presently, through general acceptance, most likely to be used as Tin Lead solder replacements?
- What tests are applicable to make an accurate determination of the differences (if any) in the properties of the most likely candidates?

## Alloy Choice

The majority of potential “standard” replacement alloys are composed of Tin, Silver, and Copper with Silver varying between 3 and 4% and Tin varying between 95.5 and 96.5%. The current “front runners” are (in % of Tin/Silver/Copper) the 96.5/3.0/0.5 0 (Japanese) and 95.5/3.9/0.6 (NEMI) alloys. Therefore, it should be expected that, from the cost and performance of the alloy, the Silver content should dominate. Accordingly, any comparison of alloys should be done on a material set that spans the range of Silver content from 3 to 4%. To cover that composition range the alloys chosen for testing by the IPC SPVC were:

- 96.5/3.0/0.5 Tin/Silver/Copper
- 95.5/3.8/0.7 Tin/Silver/Copper
- 95.5/4.0/0.5 Tin/Silver/Copper

## Test Regimen for Alloy Comparison

There are two major areas of concern when considering whether a standard solder replacement for the existing tin lead eutectic solder can be determined.

1. What are the relative properties of the range of candidates and how do these properties affect the performance of the candidate material in assembly?
2. Once assembly is complete, is there any significant difference in the long-term interconnection reliability performance of the candidate materials?

## Assembly Performance Comparison

A solder alloy’s assembly properties (and for this paper the term assembly will be limited to surface mount reflow assembly) are determined by the melt characteristics of the alloy and its ability to wet a substrate. The former determines the process parameters, e.g. reflow profile, for the alloy. The latter determines the ability of the alloy to form an inter-metallic bond between the substrate and components of the assembly.

After consideration the SPVC Technical Committee agreed that, as a first step in analyzing the three tin silver and copper alloys, the following tests were most suited for use in comparison of alloy properties:

- **Melt Characterization:** Differential Scanning Calorimetry (DSC, measured at rates of 3 and 10 ° C per minute)
- **Wetting Balance Responses:** Time to cross the zero line and maximum wetting force tested per IPC-TM-650, 2.4.14.2, Liquid Flux Activity, Wetting Balance Method using flux per J-STD-003A, 3.2.2, Flux. (Appendix 2)

- **Solder Spread** of a standard amount of alloy as determined by area of spread and diameter of the pattern of spread per IPC-TM-650, 2.4.46, Spread Test, Liquid or Extracted Solder Flux, Solder Paste and Extracted Cored Wires or Preforms (Appendix 3)

## Assembly Performance Testing: Statistical Procedures Used

A total of seven member companies participated in the Solder Products Value Council alloy properties comparison testing. A complete summary of the data collected can be found in Appendix 1.

Analysis of the data was done using the JMP Statistical Software Package from SAS Institute. The Tukey-Kramer Analysis of Variance Method in this software package was used to test for differences between the sets of data as submitted.

There are a variety of methods to test the differences of group means (multiple comparisons) that vary in detail about how to size the test to accommodate different kinds of multiple comparisons. The All Pairs, Tukey HSD procedure gives a test that is sized for all differences among the means. This is the Tukey or Tukey-Kramer HSD (honestly significant difference) test. This test is an exact alpha-level test if the sample sizes are the same and conservative if the sample sizes are different.

The software package also provides a visual comparison of means by way of a comparison circles plot. A comparison of each pair of group means can be done visually by examining how the comparison circles intersect. (For example see Figures 1 and 2.) The outside angle of intersection visually indicates whether group means are significantly different. Circles for means that are significantly different either do not intersect or intersect slightly so that the outside angle of intersection is less than 90 degrees. If the circles intersect by an angle of more than 90 degrees or if they are nested, the means are not significantly different.

The means comparison method can be thought of as seeing if the actual difference in the means is greater than the difference that would be significant. This difference is called the LSD (least significant difference). The LSD term is used for Tukey-Kramer intervals and in context with intervals for other tests. In the comparison circles graph, the distance between the circles' centers represent the actual difference. The LSD is what the distance would be if the circles intersected at right angles.

Examples of Statistical Analysis

Figures 1 and 2 show the graphical analysis as applied to the time to reach zero force and the maximum wetting force in the wetting balance testing. Note the overlap of the data sets indicating that there is no significant difference between the alloys as tested at this particular location. A complete summary of the alloy analysis by location is shown in Table 1 below.

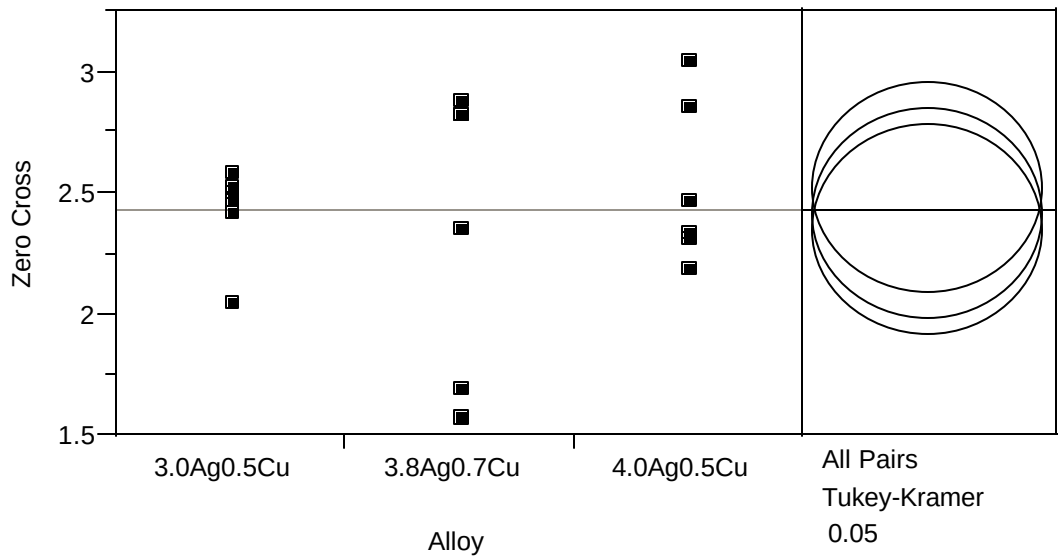


Figure 1 - Zero Crossing Time Analysis

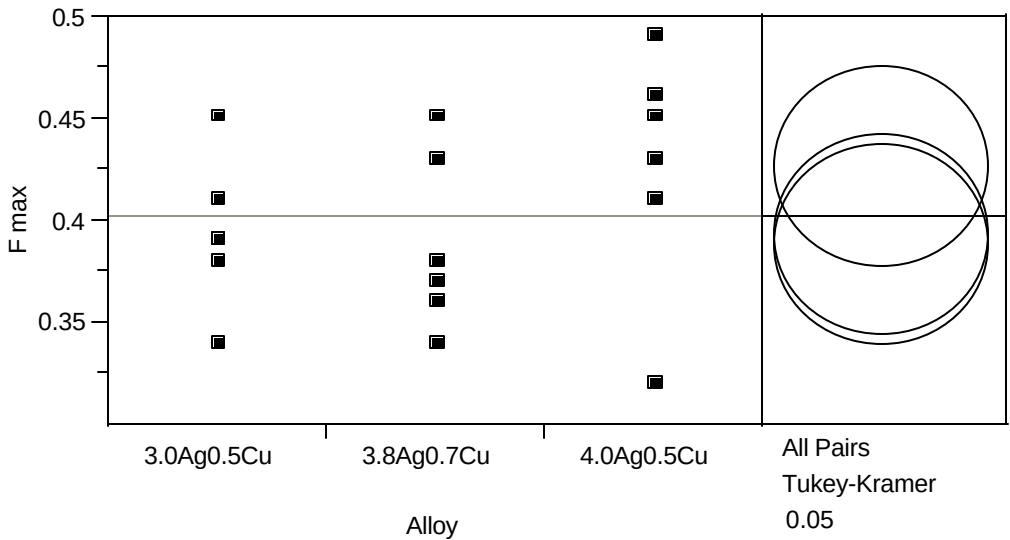


Figure 2 - Maximum Wetting Force Analysis

**Table 1 – Alloy Analysis Summary by Individual Company Site**

| Property                  | Company Designation |     |     |     |     |     |     |
|---------------------------|---------------------|-----|-----|-----|-----|-----|-----|
|                           | A                   | B   | C   | D   | E   | F   | G   |
| Zero Crossing Time (secs) | NSD                 | NSD | NSD | SD  | NSD | NSD | NSD |
| F Max (nM)                | NSD                 | NSD | NSD | NSD | NSD | NSD | SD  |
| Wetting Diameter (mm)     | NA                  | SD  | SD  | NSD | NA  | NSD | NSD |
| Melt Temperature ©        | NA                  | SD  | NSD | NA  | NSD | NSD | SD  |

Key:

NA = Parameter not measured.

NSD = Not Statistically Different

SD = Statistically Different

The results of this round robin test, as analyzed by the “JMP” package, indicate that for the majority of parameters measured there is no significant difference in the alloys within a specific test site. Table 2 below shows a similar comparison done by alloy for all locations and a comparison for all parameters by company.

An illustration of the comparison of test results by alloy for all locations and by company for all alloys is shown in Figures 3 and 4 below for wetting force and zero crossing time.

As can be seen from Table 2 and Figures 3 and 4 the greatest difference between test results is due to the location of the test. A comparison of all alloy results indicates that alloy differences are small when compared to the variability of the test locations. As was noted above, within a single location the difference between alloys is generally not significant.

**Table 2 - Analysis Summary by Alloy and Company**

| Property                  | Difference by Alloy | Difference by Company |
|---------------------------|---------------------|-----------------------|
| Zero Crossing Time (secs) | NSD                 | SD                    |
| F Max (nM)                | NSD                 | SD                    |
| Wetting Diameter (mm)     | NSD                 | SD                    |
| Melt Temperature ©        | NSD                 | SD                    |