Temperature Selection for Wave Soldering with Lead-Free Alloys

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Wetting balance testing established the best wave soldering temperatures for several lead-free alloys with a typical low-solids, no-clean flux.

Wetting balance has long been a useful laboratory test for evaluating solder wetting properties as a pre-screen for what can be expected in a printed circuit assembly process on the production floor. Three materials are required to conduct a wetting balance measurement: a substrate, flux and solder. Accordingly, three principal applications exist for wetting balance testing. The substrate can be an area of metallization on a printed circuit board surface, an electronic component lead or its termination. Wetting balance testing is used to assess the solderability of the metallic surface. The test procedures are detailed in IPC J-Standards –002 and –003. The wetting balance test can also be used as a screening tool to evaluate the wetting efficiencies of alternative soldering flux compositions.

Recently, wetting balance was used to evaluate the wetting properties of several alternative solder alloys and, in particular, lead-free solders. This testing was part of a comprehensive study of lead-free reflow and wave soldering, whose purpose was to evaluate materials compatibility, solderability and solder joint quality. The study included a broad mix of alloys, solder fluxes, solder pastes, board finishes, surface-mount and through-hole components and a specially designed test board. The wetting balance instrument was chosen to determine the appropriate solder pot temperatures for the various lead-free alloys to be used in the wave soldering phase of the study.

Wetting Balance Test Methodology

Five lead-free solder alloys were evaluated, including binary alloys of tin with silver and copper, a ternary alloy of tin/silver/copper and quaternary alloys of tin/silver/copper with bismuth and antimony. Eutectic tin/lead solder was included in the study for comparison. The specific alloys evaluated and their melting ranges are shown in Table 1.

Test substrate

The test substrates were copper coupons with dimensions of 1.0 in. × 0.5 in. and 0.005-in. thickness; the coupons complied with ISO 1634-CU-ETP condition HA, per IPC-TM-650. The coupons were precleaned as follows:

- degrease in boiling isopropyl alcohol
- deoxidize with copper surface conditioner

Alloys	Melting Range
Sn63/Pb37	183°C
Sn99.3/Cu0.7	227°C
Sn96.5/Ag3.5	221°C
Sn95.5/Ag4/Cu0.5	217° to 218°C
Sn96/Ag2.5/Bi1/Cu0.5[1]	214° to 218°C
Sn96.2/Ag2.5/Sb0.5/Cu0.8[2]	210° to 216°C

1. U.S. Patent #4,879,096 2. U.S. Patent #5,405,577

TABLE 1: Alloys tested.

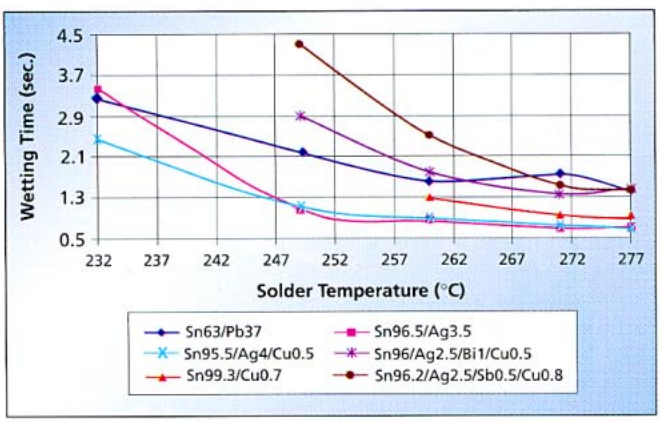

FIGURE 1: Wetting time for each alloy with test flux and clean copper.

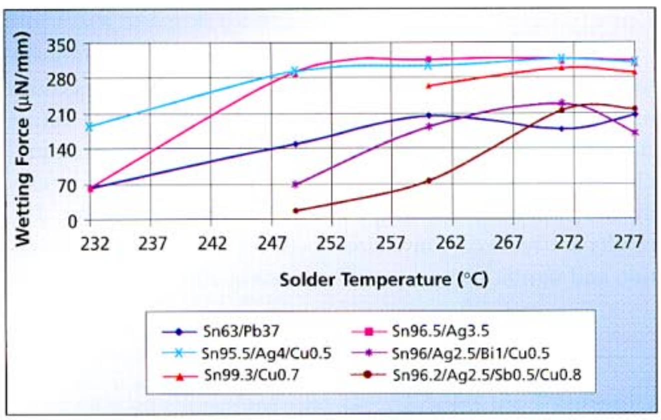

FIGURE 2: Wetting force for each alloy with test flux and clean copper.

The results indicated that 271°C appeared to be an appropriate solder pot temperature for the lead-free alloys when a low-solids, no-clean rosin type flux was used.

- rinse in deionized water
- final rinse in isopropyl alcohol.

The wetting balance testing was conducted with freshly cleaned coupons and clean coupons that were oxidized for one hour at 100°C.

Test parameters

Solder wetting measurements were conducted using a wetting balance tester. The instrument's solder pot was filled consecutively with each alloy to be tested. Coupons were dipped in a low-solids no-clean test flux to a depth of 0.1 in. The coupons were next preheated by suspension 0.1 in. above the solder pot for five seconds. They were then immersed in the solder pot to a depth of 0.1 in. for five seconds. Both the immersion and withdrawal rates of the coupons from the flux and solder were 1 in./sec.

Both oxidized and non-oxidized copper coupons were used with the test flux. Testing was conducted using a range of solder pot temperatures. Fifteen test coupons were used for each combination of solder alloy, solder pot temperature and coupon surface condition.

Test Results

Two measurements were recorded for each wetting balance test: wetting time and wetting force. The wetting time recorded is the time required to cross the zero wetting force axis in seconds. A low wetting time is desired. The wetting force recorded is the final wetting force in µN/mm. A high wetting force is desired.

The wetting balance results obtained from this study are presented in Figures 1 to 4. Each data point represented the average of 15 readings. Standard deviations in test data were low for each test condition.

Figures 1 and 2 represent the wetting time and wetting force results for each test alloy and the test flux, using clean (non-oxidized) copper. Figures 3 and 4 represent the wetting time and wetting force results for each test alloy and the test flux, using oxidized copper.

The results indicated that 271°C appeared to be an appropriate solder pot temperature for the lead-free alloys when a low-solids, no-clean rosin type flux was used. With clean copper and low solids flux, the wetting time generally decreased with the lead-free alloys until 271°C was reached, and then the wetting time leveled off or increased slightly with higher temperature. Similarly, wetting force generally increased to 271°C and then leveled off or decreased slightly with higher temperature.

The binary and ternary tin, silver and copper alloys produced faster wetting times and higher wetting forces than the quaternary alloys and the control tin/lead alloy. The tin/copper alloy required a minimum temperature of 260°C to attain positive wetting force. The quaternary alloys required a minimum temperature of 249°C to attain positive wetting. The tin/silver and tin/silver/copper alloys attained positive wetting at the lowest test temperature of 232°C, as did the tin/lead control solder.

With oxidized copper and low solids flux, the results with the different alloys were more closely bunched together. With oxidized copper substrates, a solder pot temperature of 271°C generally gave better results than at lower temperatures. However, some alloys gave marginally better results at the maximum test temperature of 277°C.

The binary and ternary tin, silver and copper alloys yielded slightly faster wetting times and slightly higher wetting forces with clean copper than with oxidized copper. This result was expected; oxidized copper was more difficult to wet in a metallurgical sense with solder. However, the trend was just the opposite with the quaternary alloys and the tin/lead control. They actually yielded slightly better wetting balance results with oxidized copper than with clean copper.

Conclusions

Wetting balance testing indicated that 271°C was an appropriate solder pot temperature for the lead-free alloys evaluated when a low-solids, no-clean rosin type flux was used. The tin/silver, tin/copper and tin/silver/copper alloys generally produced the fastest wetting times and maximum wetting forces. The suitability of the individual lead-free alloys and solder pot temperatures must be verified in an actual wave soldering process evaluation using printed circuit

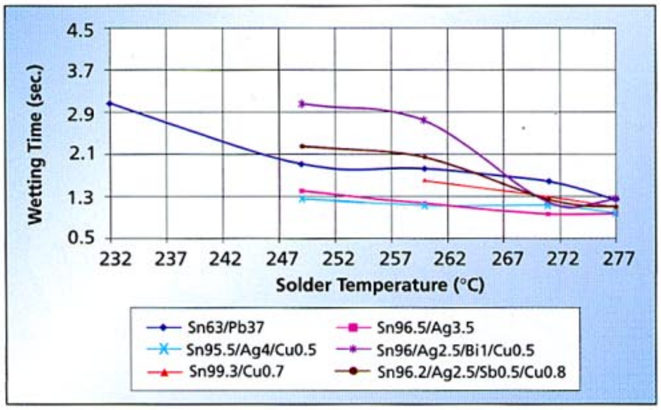

FIGURE 3: Wetting time for each alloy with test flux and oxidized copper.

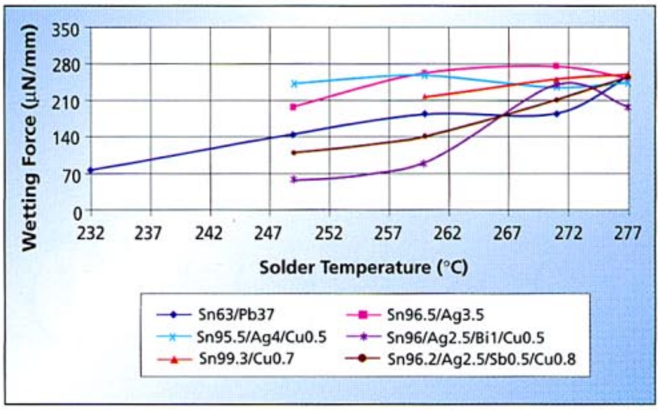

FIGURE 4: Wetting force for each alloy with test flux and oxidized copper.

boards with both through-hole and surface-mount electronic components. ■

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