# A Mechanical Evaluation of Lead Free Solder Alloys

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The transition to lead free solder alloys in electronics manufacturing has created a major concern for engineers responsible for the mechanical reliability of interconnections on electronic assemblies. Lead free solders introduce a number of different material constituents that have had little or no long term reliability testing performed.

The questions being asked by many reliability and process engineers are which lead free solder alloy should I use, and in which flux configuration? Is there a difference in performance between flux types and vendor brands? To answer these questions and understand the principle differences in tensile strength between Sn63/Pb37 and lead free solder alloys, the following test protocol was created to correlate tensile strength to wicking distance via wetting force capability.

This unusual comparison of tensile strength and wetting force capability has a defined objective to correlate wetting angle and wetting force to overall tensile strength of a solder joint. This is done primarily by correlating common measure points from different solder alloys and their specific flux configuration. This solder joint or interconnection and its corresponding wetting force capability have a direct correlation to mechanical strength and integrity.

The testing protocol for evaluating the various alloys incorporated material sets which were identified prior to testing and included multiple alloys and flux configurations. It was important to evaluate multiple variations of lead free alloys, but equally important to establish a control sample of Sn63/Pb37 (Alloy 1) to serve as a baseline. The lead free alloys evaluated (Alloys 2 - 4) were chosen for the varying copper load of the materials. A range of lead free alloys containing 0.75% to 0% copper was chosen for the test.

Pull testing utilized a mechanical pull test unit configured to hold the highest measurement reached during each test. The tensile strength value at failure was then noted and recorded. This process was completed for four coupons of each flux / alloy, totaling 16 data points for each material configuration. Additionally, optical and real time x-ray inspection was completed on one representative coupon for each material configuration. Finally, cross sections were produced utilizing the specific coupon designated for each alloy configuration. Once completed, the wicking distance from the top of the base copper surface to the top of the solder fillet was measured and recorded.

The data generated from the analysis was segregated by the corresponding test results. The categories of quantitative results were tensile strength, wicking distance, wetting force, and time to wet. Qualitative characteristics that were assessed included voiding from x-ray images and external appearance from visual inspection.

Visual inspection of the test coupons revealed subtle differences in surface appearance. X-ray results demonstrated a significant disparity between the lead bearing and lead free alloys. Voiding was characterized as minimal in Alloy 1. Alloys 2, 3, and 4 exhibited moderate to heavy voiding. In addition, the voiding seemed to be distributed uniformly.

Quantifiable results included tensile strength, wicking distance, and wetting characteristics. The results from the wetting balance testing are summarized in Table 1.

| | Alloy | | | |
|---|---|---|---|---|
| Characteristic | 1 | 2 | 3 | 4 |
| Time to Zero Force (sec) | 0.60 | 0.54 | 0.48 | 0.52 |
| Time to 2/3 Max Force (sec) | 0.92 | 0.81 | 0.77 | 0.78 |
| Maximum Force (mg/mm) | 40.16 | 38.35 | 41.52 | 37.65 |

**Table 1.** Wetting Balance Results

A summarization of the Pull Test results is listed in Table 2. Alloy 1, lead bearing, again performed the best of all alloys tested. Not only was the average tensile strength of the lead bearing solder superior to that of the lead free solders, but also the standard deviation was much smaller. This confirms that even at the manufacturers recommended temperature profile, the lead free solders have a smaller manufacturing process window. The tensile strength of the alloys did increase proportionally to the decreasing amounts of copper. Alloy 4, which contained no copper, demonstrated the highest tensile strength. Conversely, the lead free alloy with the highest amount of copper at 0.75%, Alloy 2, illustrated the lowest tensile strength.

| | Alloy | | | |
|---|---|---|---|---|
| Characteristic | 1 | 2 | 3 | 4 |
| Median Pull Strength (kg) | 7.80 | 5.90 | 6.49 | 6.58 |
| Average Pull Strength (kg) | 7.77 | 5.80 | 6.47 | 6.52 |
| Standard Deviation | 0.26 | 0.67 | 0.72 | 0.58 |

**Table 2.** Pull Testing Statistics

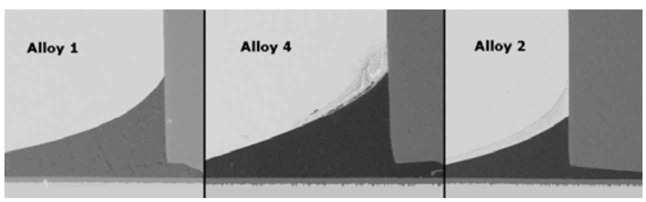
The final test that was performed was cross-sectioning samples of each alloy to assess the wicking distance up the lead. Table 3 summarizes the results from that analysis.

| | Alloy | | | |
|---|---|---|---|---|
| **Characteristic** | **1** | **2** | **3** | **4** |
| Average Pull Strength (kg) | 7.77 | 5.80 | 6.47 | 6.52 |
| Wicking Distance (mm) | 0.536 | 0.387 | 0.440 | 0.484 |

**Table 3.** Pull Test Results Summarization

A similar correlation to the tensile strength is illustrated in the wicking distance results. Samples which exhibited higher tensile strength values also demonstrated larger wicking distances up the copper lead. This suggests that the surface coverage area, larger when the solder wicks further up the lead, is the basis for the mechanical strength of the soldered interconnect.

Results of the analysis prove that tensile strength has a direct correlation to wetting angle via the z-axis height (wicking distance) of the solder fillet up the lead. Interesting to note is the observation that the highest concentration of copper in the solder paste alloys under evaluation has the lowest wicking distance up the lead. The tensile strength measurements by alloy type and flux configuration, as seen in Figure 1, shows a clear correlation between copper addition and tensile strength. The higher the concentration of copper in a solder alloy, the lower the tensile strength.




**Representative Wetting Angles**

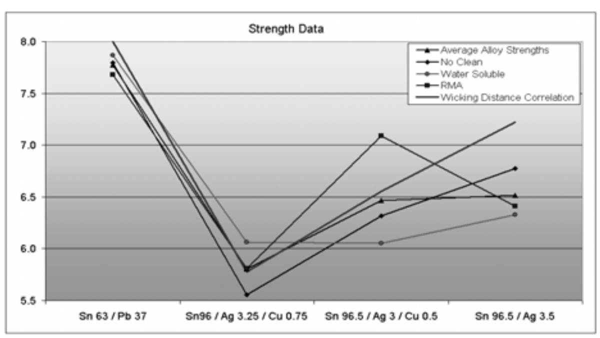



**Figure 1**

In conclusion, while many electronics manufacturers are following a path that will lead to eventual implementation of lead-free solder alloys, it is essential that adequate testing be performed to characterize the effects of such a fundamental change in the manufacturing process.

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