

Comparative Wetting Ability of Lead-Free Alloys

Understanding the wetting kinetics of lead-free alloys becomes crucial in selecting a suitable lead-free composition for assembling PCBs.

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For the last two decades, the intrinsic wetting ability of solder alloys has not been the subject of study and discussion for the reason that SnPb eutectic (63Sn37Pb) has been a commonly used composition and no choice needed to be made. With the advent of lead-free alloys, the understanding of the wetting kinetics of lead-free alloys becomes crucial to the selection of a suitable lead-free composition for assembling circuit boards, thus the assurance of overall quality of the solder joints as well as the yield of circuit board manufacturing.

Intrinsic wetting ability of solder alloys is an important performance property, which directly affects the integrity of solder interconnections. This intrinsic wetting ability also controls the production yield and throughput under the dynamic soldering process — wave soldering or reflow soldering. In addition, it is well recognized that the solderability of substrates for both PCBs and components by a given solder alloy in conjunction with the effectiveness of flux chemistry contributes to the quality of solder joints.

This study evaluates the relative wetting performance among several selected lead-free alloys, which are considered to be the most viable candidates based on combined performance properties. The alloys under this study include: 99.3Sn/0.7Cu, 96.5Sn/3.5Ag, 93.5Sn/3.5Ag/3.0Bi, 95.5Sn/4.0Ag/0.5Cu, 96Sn/2.5Ag/1.0Bi/0.5Cu, 88Sn/3.5Ag/4.5Bi/4.0In, 95Sn/0.5Cu/0.5Ga/4In, 91.4Sn/4.1Ag/0.5Cu/4.0In with Sn63/Pb37 as a benchmark.

Test procedure and results

A wetting balance methodology was adopted in this study and the test specimens were prepared in accordance to IPC-TM-650. Test specimens consists of copper laminates having dimensions of 10mm x 25mm x 0.85mm (width x length x thickness). The immersion depth was 5mm with 10-second dwell time, using immersion rate of 25mm/seconds. The testing temperatures are 235°C (recommended for Sn/Pb mass soldering process), 245°C (per IPC-TM-650), 255°C and 265°C.

The flux used was Asahi's flux: FL2002, which is a RMA flux with 0.09 percent halides and 7 percent solid content. The flux is proven to be suitable for SnPb wave soldering process.

In this study, wetting time (t), wetting force (F), the effect of temperature on wetting time and wetting force were studied for the lead-free alloys of interest. Specifically, the temperature effects on the time to reach zero force, on the time to reach F_{2/3} (t_{F2/3}) and on the maximum wetting force at two seconds were monitored.

According to the generally accepted criteria per ANSI/J-STD-003 (wetting time < one second for wave soldering; wetting time < two seconds for reflow), the wetting time tested under the above-described conditions being less than one second is considered a good wetting phenomenon corresponding to a quality wave soldering process.

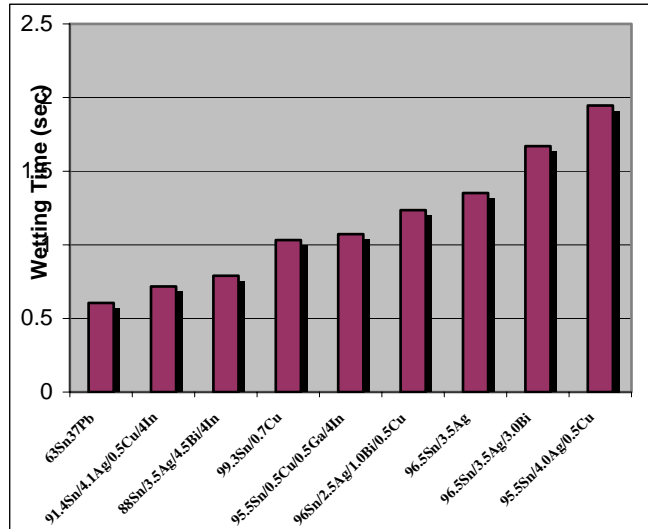


Figure 1. Wetting time of lead-free solders at 245°C

Wetting time. Figure 1 compares the relative wetting time performance among the selected lead-free alloys. It is noted that at a temperature of 245°C, 88Sn/3.5Ag/4.5Bi/4In delivered excellent results essentially in par with 63Sn/37Pb having the wetting time less than one second and that 96/Sn2.5Ag/1.0Bi/0.5Cu, 91.4Sn/4.1 Ag/0.5Cu/4.0In and 99.3Sn/0.7Cu also offered good results with the wetting time close to one second. This indicates that 88Sn/3.5Ag/4.5Bi/4In, 96Sn/2.5Ag/1.0Bi/0.5Cu, 91.4Sn/4.1Ag/0.5Cu/4.0In and 99.3Sn/0.7Cu have the superior wetting performance to 96.5Sn/3.5Ag, 93.5Sn/3.5Ag/3.0Bi and 95.5Sn/4.0Ag/0.5Cu at the operating temperature 245°C.

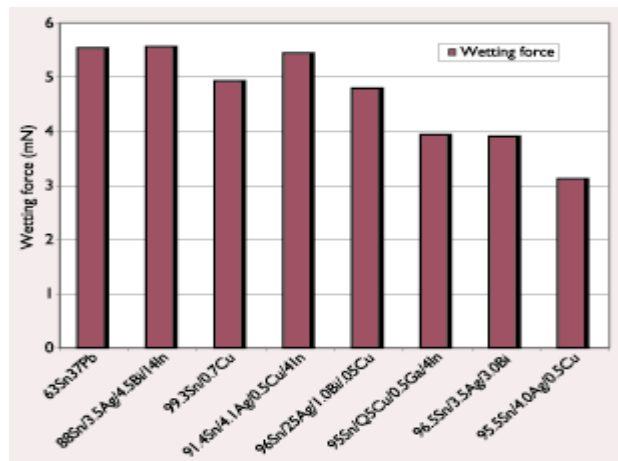


Figure 2. Wetting force of lead-free solders at 245°C

Wetting force. Wetting force measurements were obtained at 2.0 seconds at soldering temperature of 245°C. Figure 2 summarizes the relative wetting force at 245°C among the selected lead-free alloys. The results indicate that alloy 95.5Sn/4.0Ag/0.5Cu offers the lowest wetting force and 88Sn/3.5Ag/4.5Bi/4.0In and 91.4Sn/4.1Ag/0.5Cu/4.0In the highest, which is in par with that of 63Sn/37Pb.

Based on the wetting force data, it is indicative that lead-free alloys of 88Sn/3.5Ag/4.5Bi/4In and 91.4Sn/ 4.1Ag/0.5Cu/4In can perform essentially the same as SnPb alloy and that alloys of 99.3Sn/0.7Cu and 96Sn/2.5Ag/ 1.0Bi/0.5Cu close to 63Sn/37Pb and that 93.5Sn/ 3.5Ag/3.0Bi and 95.5Sn/4.0Ag/ 0.5Cu are not expected to perform as required at the temperature 245°C, which is considered to be the appropriate process temperature.

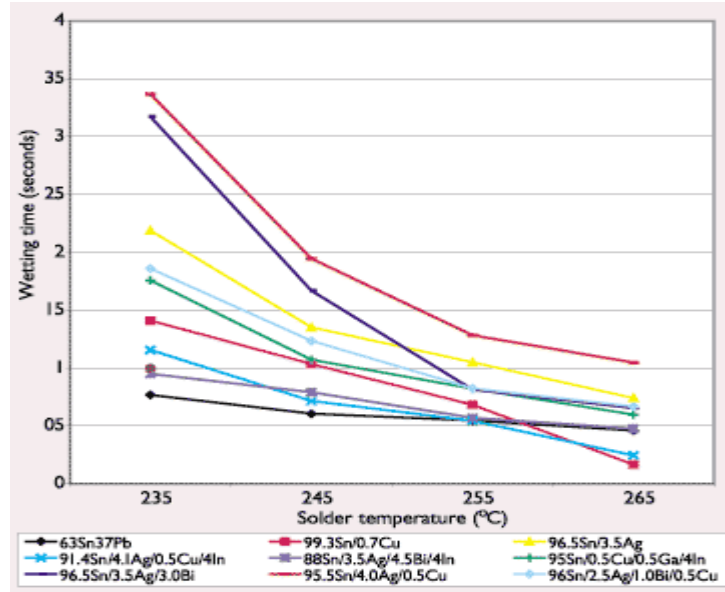


Figure 3. Wetting time of lead-free alloys at various temperature

Wetting time of lead-free alloys vs. soldering temperature. In studying the temperature effect, as expected, the test results as shown in [Figure 3](#) exhibit that the wetting time of all lead-free solders decreases with the increasing temperature as the result of preferential metallurgical reactions, surface tension and fluidity.

Solder temp °C	235	245	255	265
Wetting time (seconds)				
63Sn/37Pb	0.767	0.606	0.546	0.46
99.3Sn/0.7Cu	1.411	1.034	0.682	0.165
96.5Sn/3.5Ag	2.189	1.352	1.05	0.74
95.5Sn/4.0Ag/0.5Cu	3.368	1.946	1.284	1.048
96.5Sn/3.5Ag/3.0Bi	3.173	1.669	0.814	0.653
95Sn/0.5Cu/0.5Ga/4In	1.758	1.542	1.502	0.851
88Sn/3.5Ag/4.5Bi/4In	0.949	0.791	0.569	0.476
91.4Sn/4.1Ag/0.5Cu/4In	1.156	0.716	0.544	0.244
96Sn/2.5Ag/1.0Bi/0.5Cu	1.86	1.235	0.824	0.668

Table 1: Wetting Time of Lead-free Alloys vs. Temperature

[Table 1](#) summarizes the wetting ability of the selected lead-free alloys in response to soldering temperature. It is depicted that at a temperature of 235°C, 96Sn/3.5Ag,95.5Sn/4.0Ag/ 0.5Cu and

96.5Sn/3.5Ag/3.0Bi have too sluggish wetting kinetics and that only 63Sn/37Pb and 88Sn/3.5Ag/4.5Bi/4In have achieved the wetting time criteria per ANSI/J STD-003 (< one second for wave soldering). As the temperature increased to 245°C, 88Sn/3.5Ag/4.5Bi/4In, 91.4Sn/4.1Ag/0.5Cu/4In and 96Sn/2.5Ag/1.0Bi/0.5Cu having the wetting time very close to one second is expected to have a good wetting property. In the case of 99.3Sn/0.7Cu, its wetting time is very close to one second at 245°C and that as temperature increases to 255°C its wetting ability increases. This depicts that this alloy may have a good wetting at a temperature above 245°C.

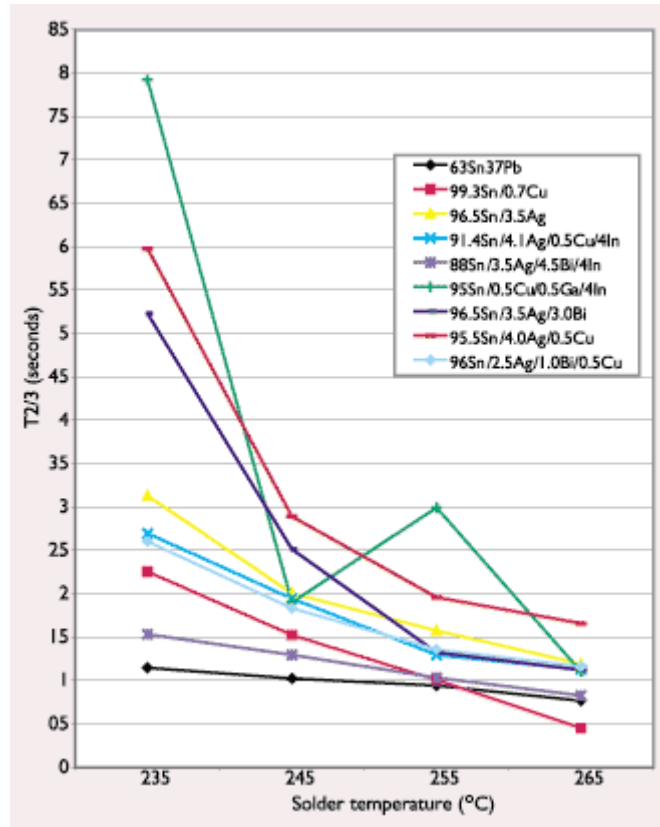


Figure 4. Comparison of t F2/3 of lead-free solders

Wetting time to 2/3 max force. It is recommended that the time to 2/3 max force (t F2/3) should be less than two seconds in order to achieve good solderability for wave soldering process. At measuring the wetting time to 2/3 maximum force, 93.5Sn/3.5Ag/3Bi and 95.5Sn/4.0Ag/0.5Cu solders displayed a longer wetting time than two seconds over the range of temperatures tested (235°—265°C), even at high temperature (>255°C). Consequently, these two solders are expected to be unsuitable for wave soldering process with pot temperature below 255°C.

At 235°C, only 63Sn/37Pb and 88Sn/3.5Ag/4.5Bi/4In is able to have t F2/3 < two seconds. As the temperature increases to 245°C, 99.3Sn/0.7Cu, 91.4Sn/4.1Ag/0.5Cu/4In and 96Sn/2.5Ag/1.0Bi/0.5Cu are able to obtain t F2/3 < two seconds. At 255°C, all the lead-free alloys managed to achieve a t F2/3 < two seconds.

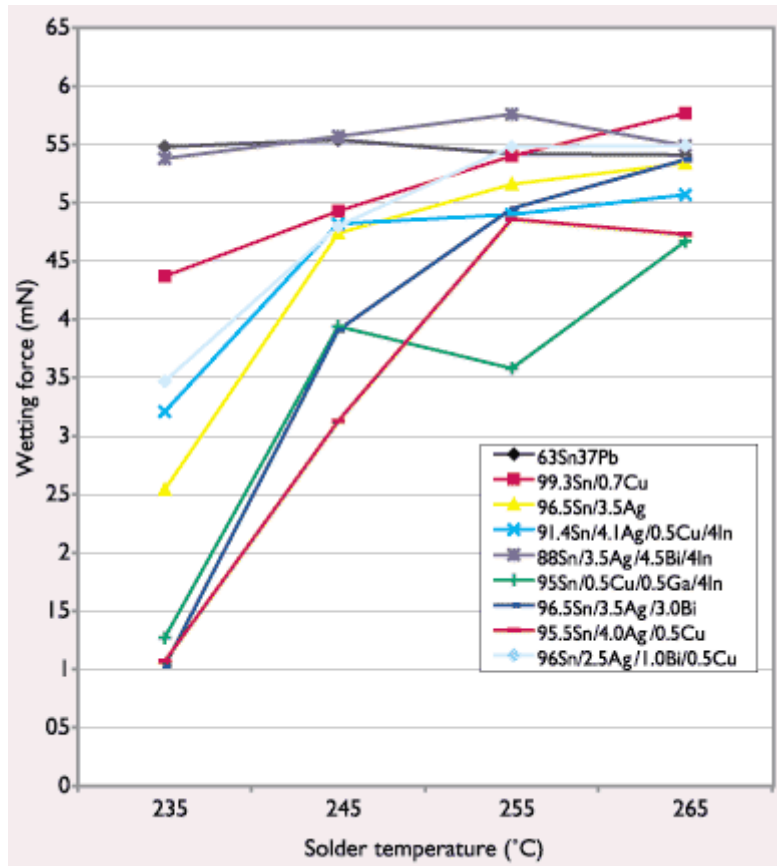


Figure 5. Comparison of maximum wetting force of lead-free solders

Maximum wetting force. Figure 5 exhibits the maximum wetting force at two seconds over the temperature range of 235°— 265°C. There is no specific standard that sets a criterion for the value of the maximum wetting force, yet 95.5Sn/4.0Ag/0.5Cu and 95.5Sn/ 3.5Ag/3.0Bi showed the lowest wetting force and 88Sn/3.5Ag/4.5Bi/ 4In the highest wetting force in the temperature range of 235°— 245°C.

As shown in Figure 5, among the lead-free solders tested, 88Sn/3.5Ag/ 4.5Bi/4In not only delivered the highest wetting force, but also equaled to that of 63Sn/37Pb. Only when temperature is as high as 265°C, the wetting force of other lead-free solders approaches the level of 63Sn/37Pb. In general, the maximum wetting force of 99.3Sn/0.7Cu, 96.5Sn/3.5Ag, 96Sn/ 2.5Ag/1.0Bi/0.5Cu, 88Sn/3.5Ag/4.5Bi/ 4.0In and 91.4Sn/4.1Ag/0.5Cu/4.0In are clearly higher than 93.5Sn/ 3.5Ag/3.0Bi and 95.5Sn/4.0 Ag/0.5Cu.

Summary and conclusions

The wetting time and wetting force reflect the relative wetting performance among the lead-free alloys. More pronouncedly, they correlate to the spread and fillet formation under a given soldering process. As expected, the process temperature affects the wetting results and an alloy's wetting ability increases with increasing temperature until approaching a relatively steady state. Using an RMA flux, the test results demonstrate that 88Sn/3.5Ag/ 4.5Bi/4In is able to display the comparable wetting ability as 63Sn/37Pb at 235°C; that Sn91.4/Ag4.1/ Cu0.5/In4 and 96Sn/2.5Ag/ 1.0Bi/0.5Cu displays a good wetting ability at 245°C; that Sn99.3/Cu0.7 solder

reaches a good wetting at a temperature higher than 245°C; and 95.5Sn/4.0Ag/ 0.5Cu, 95.5Sn/4.5Ag/3.0Bi and 96.5Sn/3.5Ag cannot deliver a good wetting until the soldering temperature approaches 255°C.

Consequently, lead-free alloys, such as 95.5Sn/4.0Ag/ 0.5Cu, 95.5Sn/4.5Ag/3.0Bi and 96.5Sn/3.5Ag are not expected to deliver a good wetting under the commonly used wave and reflow soldering temperature (equal to or below 240°— 245°C) with existing equipment and process settings.

Furthermore, at 265°C, the test results showed that all lead-free alloys tested under this study have a wetting time less than one second. This depicts that all of these selected lead-free alloys can achieve an acceptable wetting at this high temperature.

Overall, this systematic study demonstrates that 96Sn/2.5Ag/1.0Bi/0.5Cu, 88Sn/3.5Ag/4.5Bi/4.0In and 91.4Sn/4.1Ag/0.5Cu/4.0In are the top performers in wetting ability.

The trends and the relative performance of the lead-free alloys are consistent across the established wetting parameters tested under this study. It is observed that these wetting parameters as obtained by the wetting balance technique are congruent with the evaluation results in an actual wave soldering process in terms of wetting ability and fillet formation.

The alloy systems and the composition of alloys in a system predominately control the wetting performance at a given temperature. Since 88Sn/3.5Ag/ 4.5Bi/4In and 91.4Sn/4.1Ag/ 0.5Cu/4In demonstrated comparable wetting properties to 63Sn/37Pb at a temperature range between 235 and 245°C, these two alloys are considered to be a drop-in replacement for 63Sn/37Pb for both wave soldering and reflow process.

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