A Comparison of Leading Lead-Free Alloys

By karl Seelig

Volume 1, Issue 1 — September 1998

Based on recent market developments, it appears that the choice of suitable lead-free alloys to replace Tin-Lead for electronics assembly is narrowing. Three candidates have emerged as potential standards for the industry. They are the Tin-Copper eutectic (Sn 99.3, Cu .7), the Tin-Silver eutectic (Sn96.5, Ag3.5), and CASTIN (Cu .8, Sb .5, Ag2.5, Sn96.2). In order to make objective comparisons between the three alloys, extensive testing covering several variables was conducted.

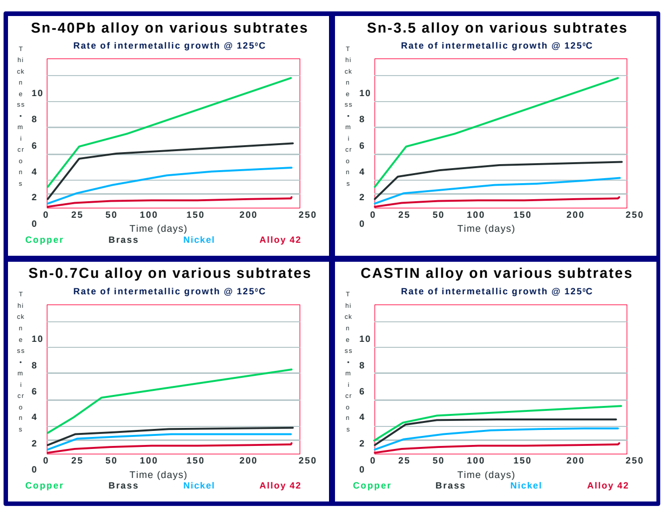
The first test concerned melting points, an important distinguishing characteristic among these alloys (see Figure I on following page), as temperature is a critical factor in regard to component and equipment specifications.

CASTIN® Melting Point Comparison

CASTIN®	216°C
Sn96 / Ag4	221°C
Sn99.1 / Cu.9	227°C

Of the three, CASTIN offers the lowest liquidus temperature (and the closest to the classic Sn63 Pb37 alloy), with a melting point of 216 degrees C.

A second area of concern relates to inter-metallic growth rates during reflow. Figure 2 compares the test results among the three alloys at 125 degrees C. It is interesting to note that the Tin-Silver (Sn96) alloy featured growth rates similar to the Tin-Lead (Sn63) alloy currently used in most assembly operations. The Tin-Copper (Sn99.3) alloy suffered from relatively high copper inter-metallic growth as well. CASTIN®, which has a similar amount of copper to the Tin-Copper alloy, enjoyed significantly lower rates of inter-metallic growth than the other two alloys.



Graph Generated by ITRI

It is suspected that the addition of Antimony as a dopant in CASTIN inhibits Copper-Tin inter-metallic growth. It has also been known for many years that Antimony helps improve the thermal fatigue resistance of the alloy.

Based on the above criteria, the Tin-Copper alloy was not regarded as a viable replacement for the Sn63 alloy, due to poorer wetting characteristics and higher temperature requirements than the other two candidates.

Physical Comparison

	CASTIN®	Sn96
TENSILE		
UTS (ksi)	5.56	5.91
Yield Strength (ksi)	4.03	4.07
Young's Module E (msi)	4.3	5.74
% Elongation	50.00	43.66
COMPRESSION		
Stress @ 25% Strain (ksi)	10.07	9.88
Yield Strength .2%Strain (ksi)	4.53	4.84
Young Modules	10.89	16.60
HARDNESS		
	13.5	12.2

Figure 3 offers a physical comparison between CASTIN and Sn96. The alloys looked very similar on this basis, nearly identical in fact. However, when the fatigue testing results were compared, Sn96 failed on one of the runs, while CASTIN passed on all three. As 10,000 cycles represented a passing mark, Figure 4 shows where Sn96 failed at 6,267 cycles. The passes that were recorded for the Sn96 alloy were marginal at best.

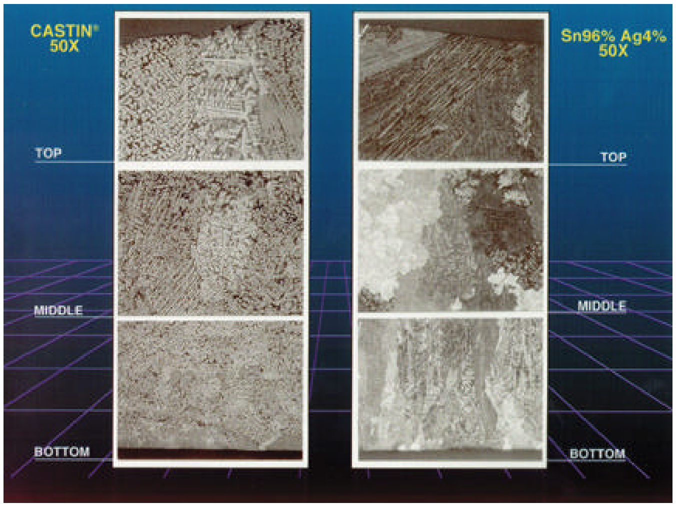
Fatigue Test Results

	CASTIN®	Sn96
Numbered Cycles to Failure	11,194	10,003
(Failure, Load Amplitude Dropped >20%)	26,921	6,267
	24,527	11,329

According to ASTME 606, 1Hz triangular waveform oscillated between .15% strain and -.15% strain.

Microstructures were examined in Figure 5 in an attempt to better understand the failure, and this is where a condition of serious concern became evident. The photos shown are of 2 bars of solder (one CASTIN, the other Sn96) that were melted and then subjected to different cooling rates. The CASTIN alloy showed a consistent, leafy, dendritic structure, regardless of the cooling rate used. The SN96, on the other hand, went through three different phases, depending on the cooling rate. It was this variance in structure through the cooling period that was felt to have been the cause of the failure in the fatigue test.

This issue raised serious practical concerns; namely, that depending on the size and location of a component on a board, structural weaknesses could actually occur in the solder interconnect, leading to field failure.



The final consideration when comparing CASTIN to Sn96 is in the cost of metals. Figure 6 shows the pure cost of elemental metals as well as the raw material cost of the final alloys. CASTIN is considerably less expensive than Sn96- the difference is over $1.00/lb, or nearly 20%.

Cost of Pure Metals (per lb.)

CASTIN®	Sn96
$4.61	$5.77

Based on Metal Costs 1/22/98

Silver	$85.31 per lb.
Tin	$ 2.46
Antimony	$ 1.02
Copper	$ .77

This difference represents dramatic savings for wave soldering and hand soldering operations, and results in a substantially lower cost for SMT grade solder pastes as well.

In conclusion, it was determined that CASTIN represents a better choice over the other leading candidates in terms of temperature, physical characteristics, fatigue resistance and grain structure phase stability.

As a final note, CASTIN® has also been used successfully in flip chip attach, showing both good joint strength and low alpha emission. CASTIN also has passed thermal cycling of -40+125 for 1000-1500 hours and -40 +85 for 840 cycles.

For more information on the subject of lead-free alloys, contact the author at 1-800-CALL-AIM.