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Effect of Soldering Method, Temperature, and Humidity on Whisker Growth in the Presence of Flux Residues

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Abstract
Since the electronics industry moved to lead-free solders that typically have a tin content of more than 95% there has been concern about the possibility of circuit malfunctions due to whisker growth. It is now generally accepted that whisker growth is a response to compressive stress within the tin crystal and the challenge is to identify and eliminate or at least minimize the processes that can generate such stress. Corrosion has been identified as one source of that stress and in this paper the authors report a study directed at identifying the relationship between the extent of corrosion and the concomitant whisker growth. Printed circuit coupons with an OSP finish were soldered with SAC305 solder using wave, reflow, and hand soldering methods with flux formulations typical of current commercial practice. These coupons, soldered but without components, were exposed to three environments for up to 3000 hours: 40°C/95%RH, 60°C/90%RH and 85°C/85%RH. As well as recording the location of whiskers, their density, and length as a function of time, the extent of corrosion of the solder after 1000, 2000 and 3000 hours was measured by cross-sectioning. The ultimate determinant of whether or not whiskers appeared was the environment to which the test pieces were exposed. The highest incidence (whiskers per unit area), fastest growth rate, and greatest length occurred on test pieces exposed to 85°C/85% RH. Whiskers occurred later, at a lower incidence, and grew more slowly at 60°C/95% RH but even after 3000 hours no whiskers were detected on test pieces exposed to 40°C/95% RH. The incidence and growth rate of whiskers was found to vary with the soldering method and the type of flux. Whisker growth occurred earliest on the test pieces that had been wave soldered. Geometry was found to have an effect with the concavity created on the edges of traces by the etching process apparently acting to focus the compressive stress and accelerate whisker growth in that area. The authors relate these trends in whisker growth to observations of the concurrent corrosion of the solder which in turn is related to the type of flux used. A preliminary conclusion is that the likelihood of whisker growth occurring on lead-free assemblies soldered using no-clean technologies can be significantly reduced by using a flux which does not promote the sort of corrosion that can generate compressive stress in the solder.

Key Words: Whiskers, Corrosion, Lead-free Solder

Introduction
Although there are few confirmed reports of equipment failures due to whisker growth from solder joints rather than from electrodeposited tin finishes the possibility remains a concern for the electronics industry. It is now widely accepted that the primary driving force for whisker growth is relief of compressive stress and while it is well established that such stress can occur in electrodeposited coatings, particularly when the process is out of specification, a solder joint formed by unconstrained solidification from the molten state tends to be naturally stress-free. There are, however, ways in which compressive stress sufficient to induce whisker growth can be introduced to a solder joint. One such source of compressive stress recognized in tests such as JESD22A121, "Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes" is corrosion induced by exposure to heat and humidity.

The study reported in this paper investigated the relationship between whisker growth in conditions of heat and humidity and surface corrosion accelerated by the residues of the fluxes typically used in the three common soldering processes, wave soldering, hand soldering and reflow soldering.

Experimental Method
Alloy: Sn-3.0Ag-0.5Cu (SAC305), Sn-0.7Cu-0.06Ni-0.1Ge (SN100C®)
Test Vehicle: Interdigitated comb pattern, electrodeposited 35µm thick copper traces at 0.15 and 0.3mm spacing (Figure 1).
Soldering Methods: Solder was applied to the test vehicle by dip soldering, hand soldering and reflow soldering with a variety of commercially available wave soldering fluxes, flux cored solder wires and solder pastes using process parameters recommended for these materials (Table 1)

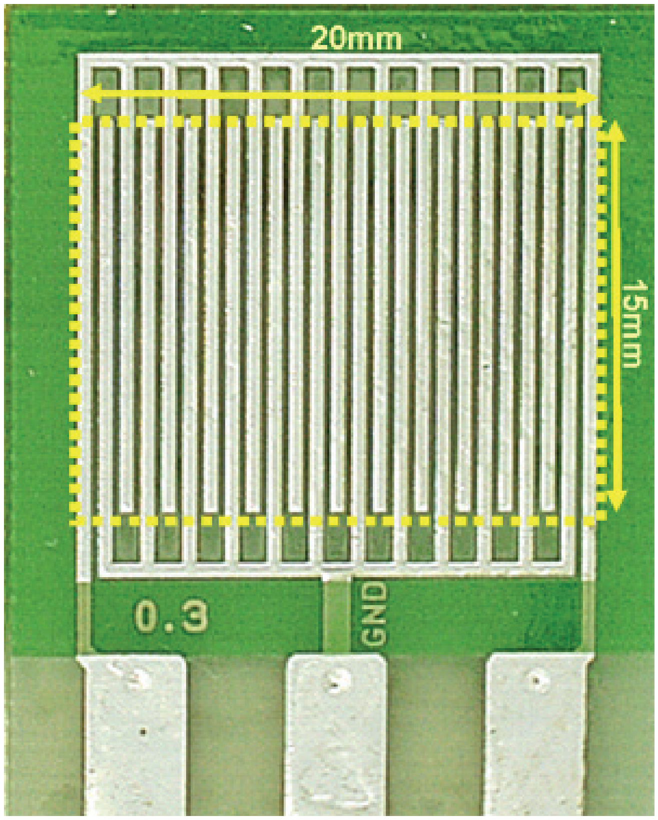

Figure 1. Test vehicle.

Exposure Environments: 40°C/95%RH
60°C/90%RH
85°C/85%RH

Inspection: Test vehicles were inspected for whiskers at up to 5000 hours.

Whisker Measurement: The area defined by the yellow dotted line in Figure 1 was inspected for whiskers. Whisker densities were determined by superimposing grids on SEM images of the traces and counting the squares in which whisker occurred. The longest whiskers in each field of view were noted and the length estimated in the SEM.

Corrosion Measurement: Figure 2 is typical of a cross-section of a soldered trace exposed to heat and humidity. Figure 3 is a magnified view of the edge of the trace where the solder is most exposed to flux residue and where most corrosion occurs. Solder corrosion was quantified by measuring on cross-sections such as this the total area of corrosion and expressing that as a percentage of the total cross-section area of the solder coating excluding the intermetallic compound at the solder/copper interface and in the matrix.

Table 1. Soldering Conditions

	Soldering Method		
	Hand	Dip	Reflow
Fluxes	A.B,C,D,E	F,G	H,K
Soldering Parameters	Tip 300°C Continuous	Solder 250°C	Ramp Profile 1.5°C/s 50s>227°C
A,B,C,D Halogenated Core Fluxes E: Halogen-free Core Flux F,G: Halogenated Liquid Fluxes H, K Halogenated Paste Medium			

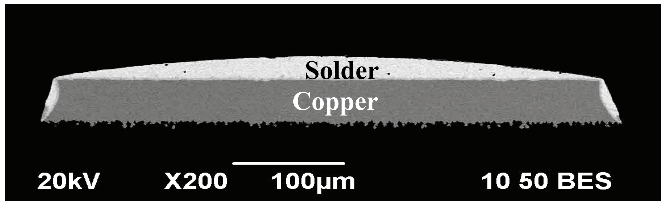

Figure 2. Cross-section of typical soldered trace

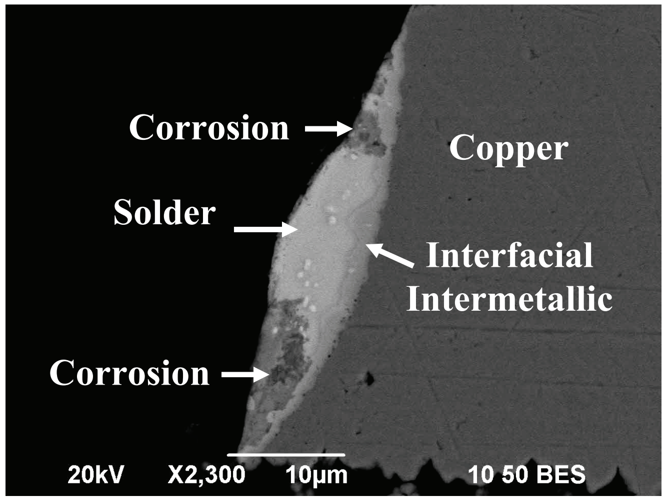

Figure 3. Cross-section of corroded solder

RESULTS
As expected the extent of corrosion increased with increasing temperature and humidity (Figure 4). Under the same environmental conditions the extent of corrosion varied with the soldering method with, on average, corrosion being greatest on the test vehicles that had been reflow soldered and least on those that had been hand soldered.

The typical distribution of whiskers is indicated schematically in Figure 5 with the greatest concentration of whiskers of the greatest length occurring on the edges.

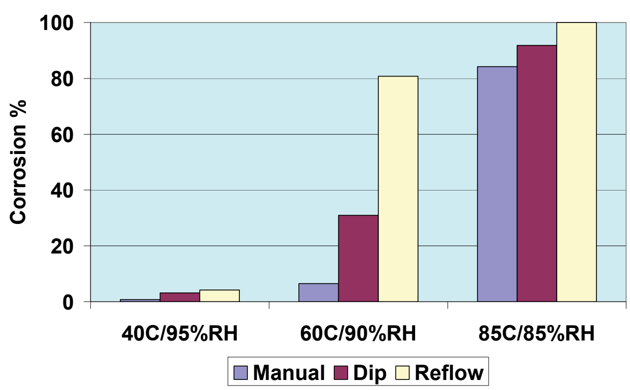

Figure 4. Corrosion at 3000h as a function of environment and soldering method.

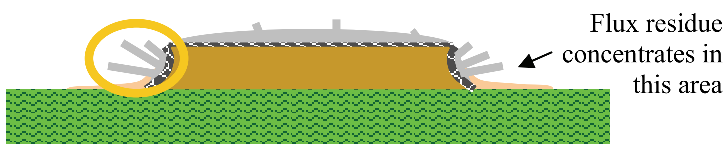

Figure 5. Schematic indication of pattern of whisker growth.

Significant whisker growth occurred only under the conditions of 60°C/90%RH and 85°C.85%RH and there is a relationship between the extent of corrosion and the maximum whisker length (Figure 6).

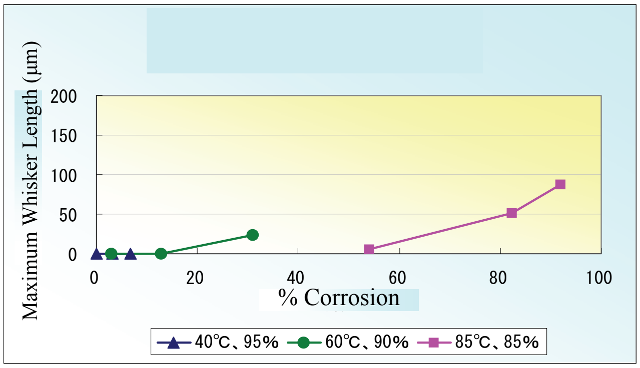

Figure 6. Maximum whisker length as a function of corrosion %

The environmental condition had a strong effect on the time to the occurrence of the first whisker (Table 2)

Table 2. Effect of environment on time to first whisker

Condition	Time	Acceleration Factor
40°C/95%RH	5000h	1
60°C/90%RH	1000-2000h	~3
85°C/85%RH	~500h	~10

The soldering method had a small but significant effect on the time to the occurrence of the first whisker (Table 3)

Table3. Effect of soldering method on time to first whisker

Method	Time	Acceleration Factor
Dip	500h	1
Hand	500-1000h	~x 1.5
Reflow	1000-2000h	~x 3

Maximum whisker length as a function of time in each of the three environments is reported on the basis of location in Figure 7. Maximum whisker length as a function of time at 85C.85%RH and location is reported on the basis of soldering method in Figure 8.

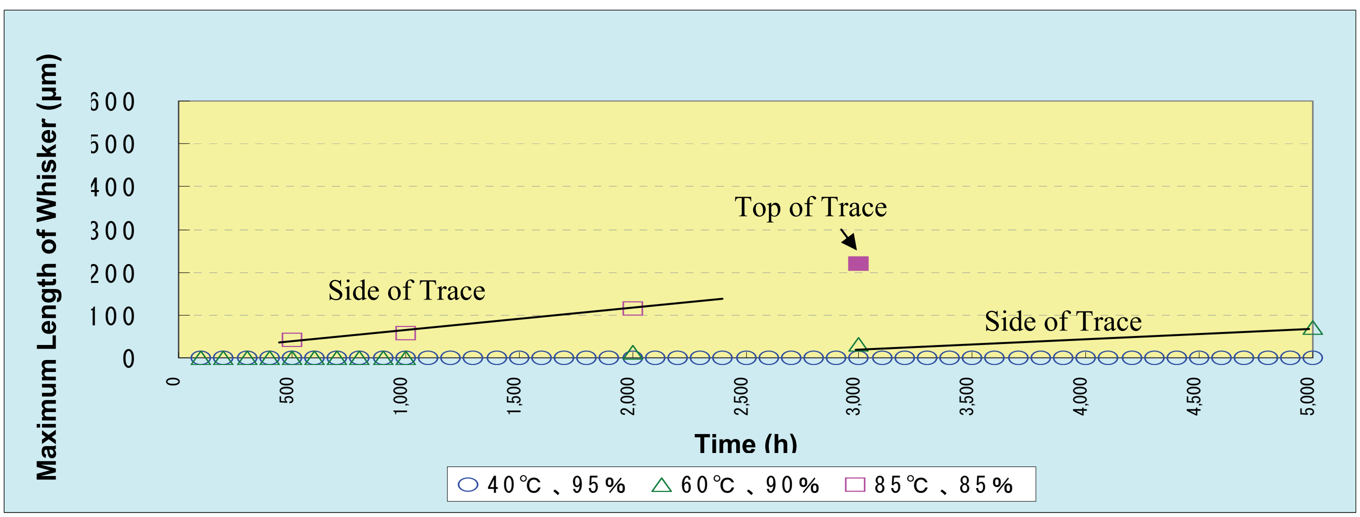

Figure 7. Maximum whisker length as a function of environment and time

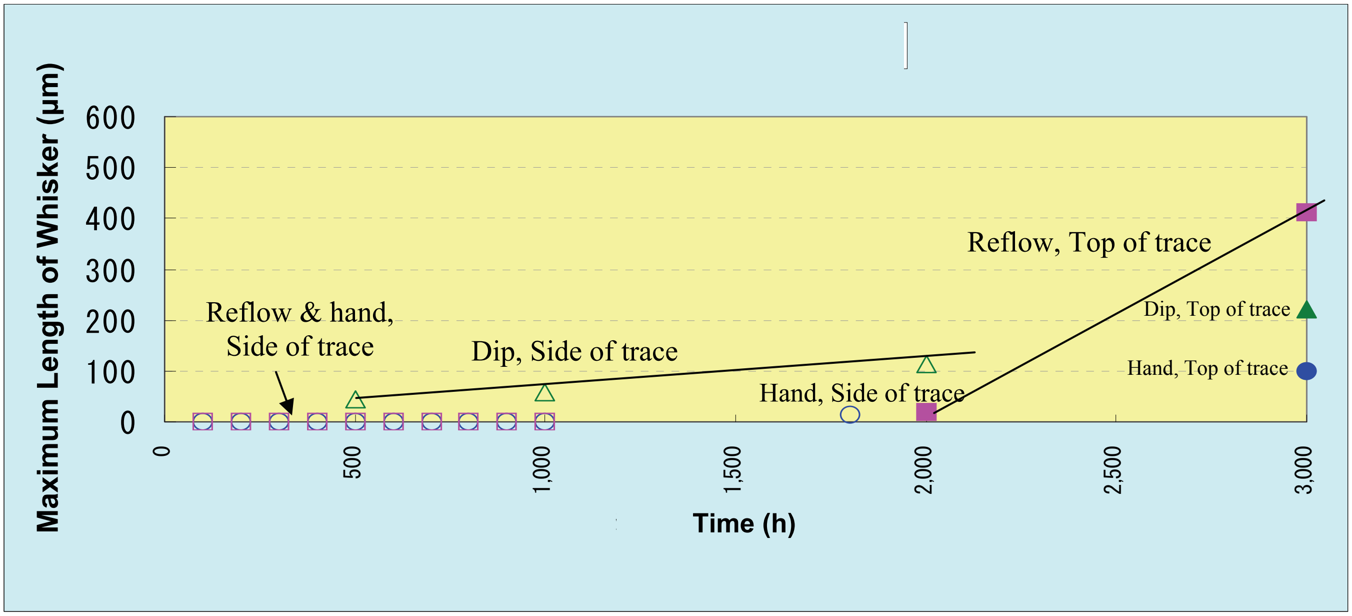

Figure 8. Maximum whisker length as a function of time at 85C/85%RH and soldering method

DISCUSSION

With no other obvious factors contributing to whisker grow the results confirm that corrosion induced by high temperature and humidity can induce of whisker growth. It can be hypothesised that the driver for the whisker growth is the compressive stresses generated by the increase in volume that occurs as the solder is converted to corrosion products.

It is generally considered that a whisker of 50µm represents a reliability risk since it has the potential to short typical circuitry. Under the conditions of this test whiskers of that length did develop in less than 1000h at 60°C/90%RH and 85°C/85%RH.

However, even at 95%RH a temperature of 40°C was not sufficient to generate whiskers of a length that could be considered a reliability risk.

The relationship between soldering method and whisker growth is presumably related to the extent to which the residue of the fluxing system used can contribute the ions that drive the corrosion process in the humid condition. There does not appear to be any obvious way in which the susceptibility of the solder itself could be affect by the method by which it is applied to the substrate as in all cases is solidifies unconstrained from the molten state.

The fact that most whisker growth occurs at the sides of the traces is presumably related to the fact that most of the flux residue ends up being concentrated in that area.

CONCLUSIONS

Under conditions of 60°C/90%RH and 85°C/85%RH corrosion that appears to be related to the character of the residues used in the soldering process can cause SAC305 solder to produce whiskers long enough to compromise circuit reliability. Where circuitry vulnerable to failure by shorts caused by whiskers is likely to be exposed to such conditions .consideration should be given to effective removal of flux residues or the selection of fluxes with residues that do not support the sort of corrosion that seems to drive whisker growth.

FUTURE WORK

Given the apparent relationship between flux residue and whisker growth under conditions of heat and humidity the possibility of formulating effective fluxes that have residues that do not promote whisker-inducing corrosion is being investigated.