Further Analysis of the Alternate Finishes Task Group Report[1] on Time, Temperature and Humidity Stress of Final Board Finish Solderability

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Abstract
The IPC study mentioned in the title looked at the effects of time, temperature and humidity on the solderability of true bare copper, immersion silver, immersion tin, organic soldering preservative, reflowed tin/lead and immersion gold/electroless nickel circuit board finishes. In the study solderability was measured by the traditional, qualitative dip and look test; by wetting balance and by SERA. This present examination centers on the results of the wetting balance and SERA work. Data for time to zero, time to two thirds maximum wetting force, maximum wetting force and the SERA parameters V2 and Vf were all examined in an attempt to see which are related. Some correlations were found that may be useful.

Introduction
The IPC Solderability Subcommittee (5-23) spun off a subgroup called the Alternate Final Finishes Task Group (5-23D) to look at the solderability of many of the different finish types that were appearing on the scene. An extensive DOE was devised to look at the effect of temperature and humidity on the solderability of these finishes. The study was to devise methods of conditioning the samples with reasonable conditions within practical lengths of time. It was NOT a comparative study of the different finishes. For the five finishes examined, only one source of each was chosen and it is known that there are several formulations of each available on the open market. So to use this data to make a blanket statement, for instance, that immersion silver is better than immersion gold would be irresponsible.

Copper coupons from a common source were coated with one of the five finishes that were to be examined: immersion tin (IT), immersion silver (IS), immersion gold over electroless nickel (NG[3]), organic soldering preservative (OSP) and reflowed tin/lead (RTL). Copper coupons with no finish of any kind (bare copper, BC) were used as a control. All of the coupons were conditioned on the bench, in humidity chambers or ovens at one location. All wetting balance testing was done at one site by one person. All of the Sequential Electrochemical Reduction Analysis (SERA) testing was done at another site by one person. It is not the intention of this paper to repeat all the details of the extensive work done in the study. This current paper makes use of the data provided to look for inter-data correlations.

The data examined were from either the wetting balance curves obtained from the solderability measurements for the metal coupons or two of the parameters (V2 and Vf) recorded from the SERA curves. Here is the whole list:

- T0 - time to reach zero buoyancy
- T2/3FMax – time to reach 2/3 of the maximum wetting force
- F2 – force at 2 seconds
- FMax – the maximum wetting force
- V2 – the reduction voltage – the most positive voltage where the oxide of interest is being reduced
- Vf - the final voltage measured in a SERA measurement run

It is hoped that this extended examination of the data will spark further examination of data various companies have available to expand our understanding of solderability.

Results
Although the documents IPC-STD-002 & 003 do not list the wetting balance as a method "with established accept/reject criteria"[2], there are several proposed pass/fail criteria listed. These include: time to zero buoyancy, the wetting force at 2 or 5 seconds, the maximum wetting force and the area under the wetting curve. The wetting curve is a plot of wetting force as a function of the time taken for the test - from the point where the sample was first touching/immersed in the liquid solder until an arbitrary completion point or when the sample was extracted from the molten solder.

The reason that so many possibilities for parameters are listed is that different groups and individuals that had input into the documents mentioned favored one parameter over another. Some favor time saying it gives a truer measure of a sample's inherent solderability, while others favor wetting force as it speaks more to the distance that the solder wets on a surface. One disadvantage of the latter is that without dividing the wetting forces by the perimeter of the wetted surface, it is not possible to compare one set of data with another. And of course a problem of comparing any set of wetting balance data with another set of data is the different thermal heat sinking abilities of the samples tested.

There are 15 possible different, binary combinations between the result variables T0, T2/3Fmax, F2, FMax, V2 and Vf. It has been possible to cut this down to a more reasonable number, based on the some of the initial correlations found.

T2/3FMax as a Function of T0

Although it is theoretically possible for T2/3Fmax to be less than T0, this condition was not seen in this study or other studies by the authors. It was decided to start looking for a correlation of these two resulting parameters because if one was found, then further correlations with other variables could be done with just one of the two. All points where no wetting occurred resulted in essentially T0 = T2/3Fmax = 5 seconds were not graphed in this examination.

For each surface finish, all plots of T2/3Fmax as a function of T0 resulted in smooth curves that could be described by a power law equation, in the form $y = -ax^2 + bx$. The equations and correlation coefficients (r^2) are given in **Table 1**. These relationships are shown in **Figures 1 – 6.**

Table 1 - Correlation Equations for T2/3FMax as a Function of T0

Finish	T2/3FMax = f(T0)	r^2
IS	$y = -0.16x^2 + 1.8x$	0.95
ENIG	$y = -0.17x^2 + 1.8x$	1
Bare copper	$y = -0.19x^2 + 2.0x$	0.98
OSP	$y = -0.21x^2 + 2.1x$	0.93
IT	$y = -0.27x^2 + 2.4x$	0.94
RTL	$y = -0.34x^2 + 2.5x$	0.89

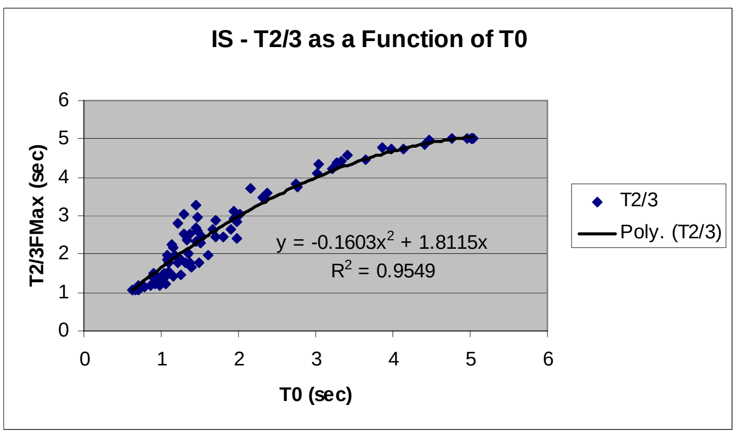

Figure 1 - Immersion Silver T2/3FMax Data Points as a Function of T0

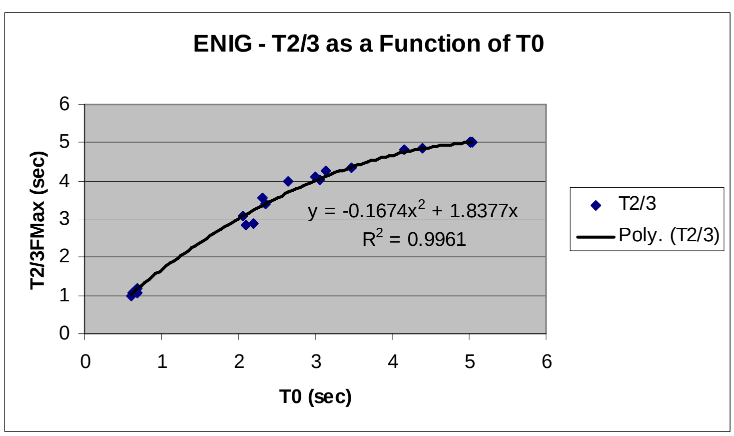

Figure 2 - ENIG T2/3FMax Data Points as a Function of T0

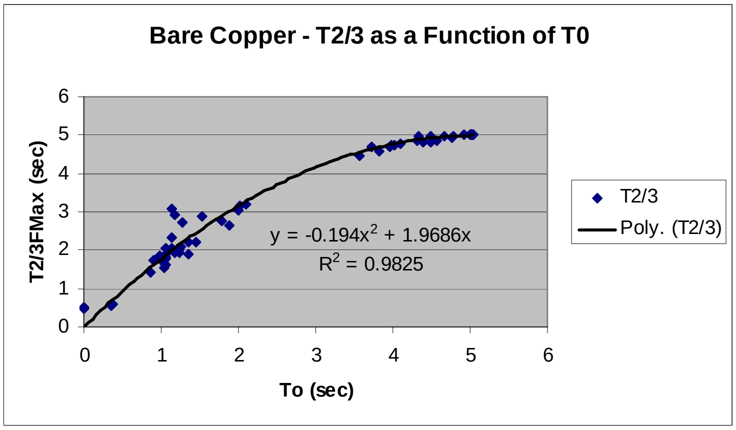

Figure 3 - Bare Copper T2/3FMax Data Points as a Function of T0

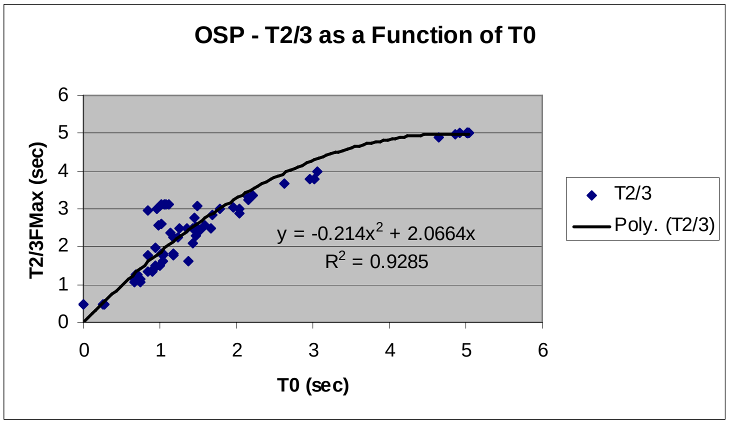

Figure 4 - OSP T2/3FMax Data Points as a Function of T0

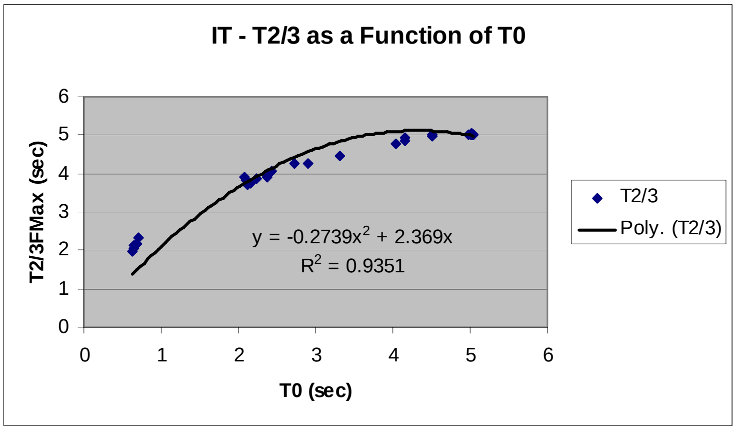

Figure 5 - Immersion Tin T2/3FMax Data Points as a Function of T0

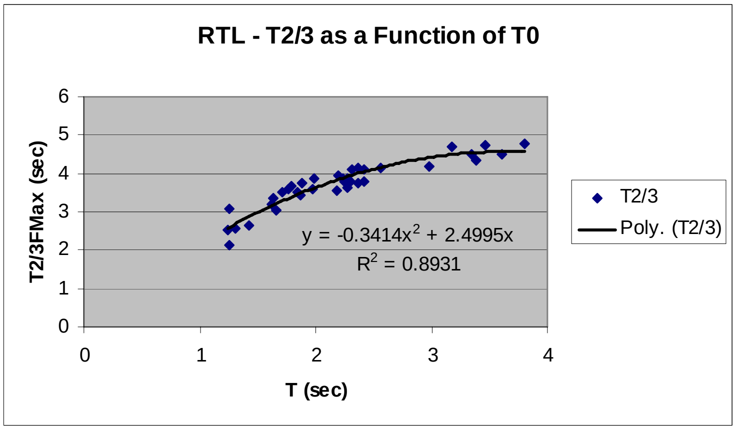

Figure 6 - Reflowed Tin/lead T2/3FMax Data Points as a Function of T0

What does this tell us?

1. There is a strong correlation of T0 and T2/3Fmax for every finish.
2. In each case that correlation takes the same general form that can be explained with a power law equation.
3. The equations can be divided into three groups – Nobel metal finishes (NG and IS), copper finishes (bare copper and OSP) and tin-containing finishes (IT and RTL).
4. In the same order as above, the slopes of the curves between 1 and 2 seconds are 1.29, 1.32; 1.43, 1.47; 1.48 and 1.59. This tells us that for curves with T0 values in the 1 – 2 second range the speed of wetting is in the order of IT>RTL>OSP>BC>IS>NG. This is of course related to "like dissolves like", melting points, solubility and the thickness of any organic coatings. The melting points for the metals are: eutectic tin/lead solder (183C), tin (232C), copper (961C), gold (1063C) and silver (1083C).
5. The number of points in the curves shows that overall there were more problems (T0 = T2/3FMax ≥ 5) with NG and IT than RTL and bare copper, with OSP and IS faring the best.

FMax as a Function of T0

Plotting FMax as a function of T0, like T2/3FMax vs. T0, again gave surprisingly good correlations, especially after removing one or two sets of data that seem to lie well off of the curves. However, unlike the T0/T2/3FMax correlations, here there is a different character to the types of curves. For RTL and IT the data can be described by second power polynomial equations, OSP requires a third power polynomial and the bare copper, IS, NG and bare copper data can be correlated using linear equations. All curves were generated using data where T0 is less than 5 seconds. The data is presented in Figures 7 – 15 below.

The equations, correlation coefficients and the data sets not used because of their distance from the curves are listed in Table 2 below.

Table 2 Correlation Equations for FMax = f(To)

Finish	**Equation**	r^2	**Data not used**
RTL	FMax = $3.48(T0)^2 – 37.5(T0) + 97.32$	0.72	all data T0> 5
RTL	FMax = $2.64(T0)^2 – 33.09(T0) + 93.66$	0.81	50/62/1000
IT	FMax = $4.38(T0)^2 – 46.03(T0) + 122.05$	0.81	72/30/8
OSP	FMax = $-2.08(T0)^3 + 10.77T0)^2 – 14.10(T0) + 66.52$	0.94	72/30/8 +5 single values
Bare Cu	FMax = -14.83T0 + 77.59	0.92	72/62/8
IS	FMax = -14.43T0 + 70.31	0.96	50/62/1000 +5 single values
NG	FMax = -17.32T0 + 84.64	0.96	72/30/8

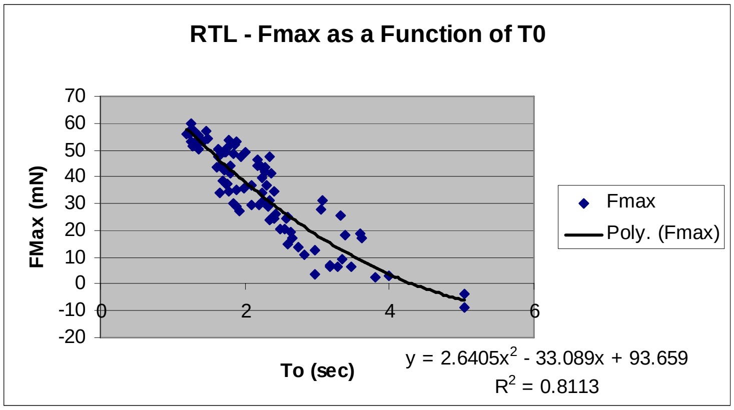

Figure 7 - Reflowed Tin/lead FMax as a Function of T0 (50/62/1000 Data Omitted)

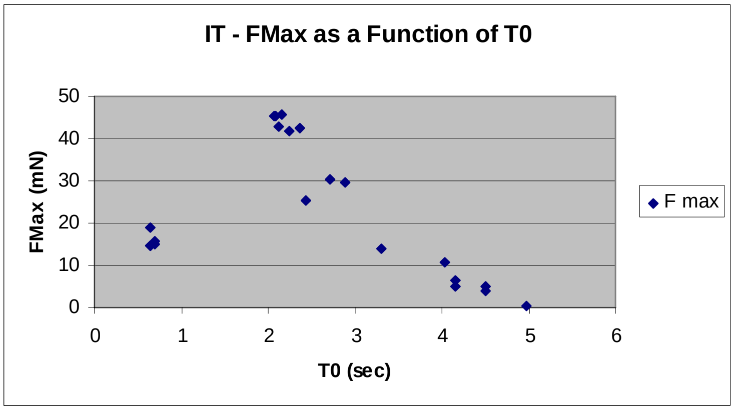

Figure 8 – Immersion Tin FMax as a Function of T0 (All Data with T<5)

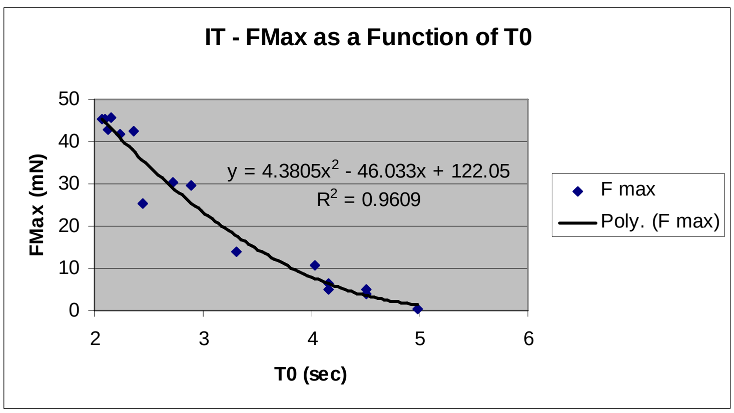

Figure 9 – Immersion Tin FMax as a Function of T0 (72/30/8 Data Set Omitted)

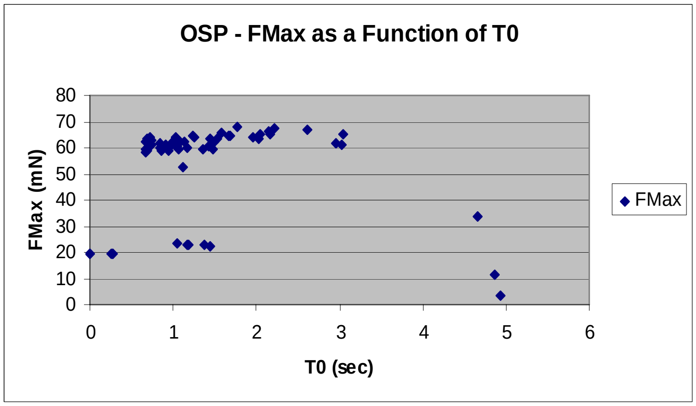

Figure 10 - OSP FMax as a Function of T0 (All Data Points)

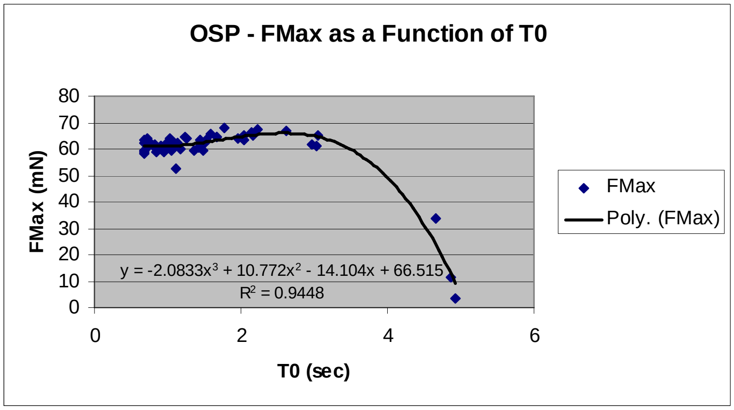

Figure 11 - OSP FMax as a Function of T0 (72/30/8 data set + 5 Single Values Omitted)

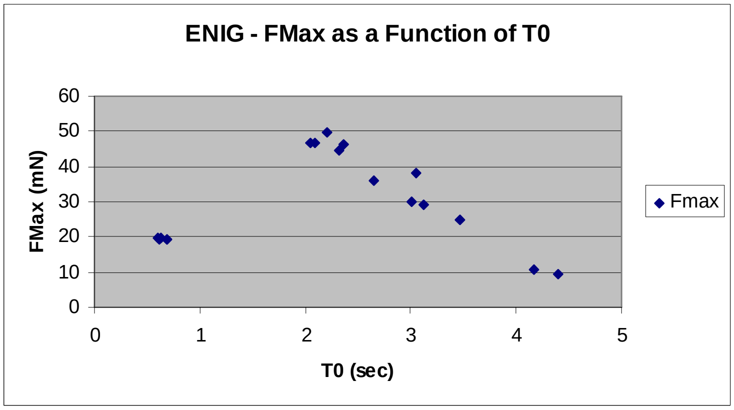

Figure 12 - ENIG FMax as a Function of T0 (All Data Sets)

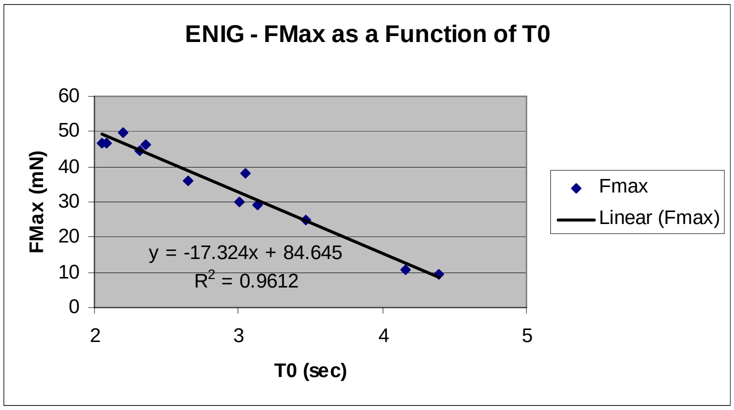

Figure 13 - ENIG FMax as a Function of T0 (72/30/8 Data Set Omitted)

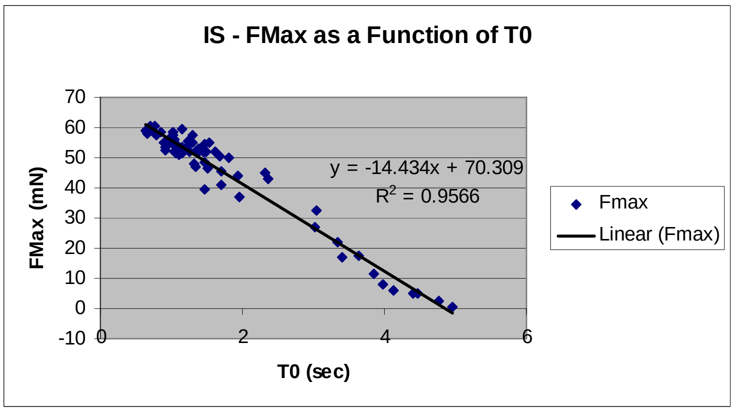

Figure 14 - Immersion Silver FMax as a Function of T0 (50/62/1000 and 95/30/504)

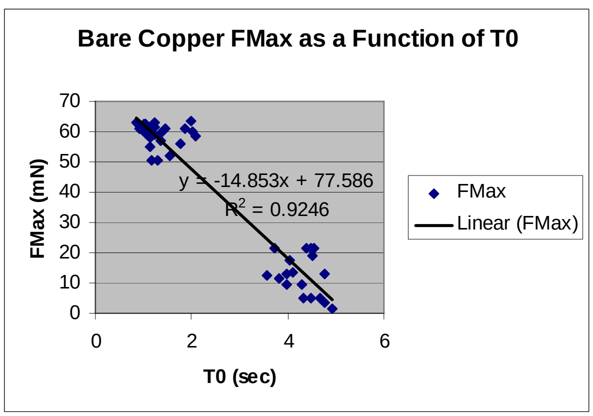

Figure 15 - Bare Copper FMax as a Function of T0 (72/62/8)

What does this tell us?

1. There is a strong correlation of T0 and FMax for every finish.
2. The correlation can be described by an equation, one of three types – linear for Nobel metal and bare copper finishes (NG, IS and BC), third power quadratic for OSP and second power quadratic for tin-containing finishes (IT and RTL).
3. The order for largest FMax values from high to lowest is OSP~BC>IS>RTL>NG>IT

The difference in the equations points to different mechanisms for wetting, with melting playing a bigger role for RTL and IT and diffusion being dominant for bare copper, silver and gold. OSP is different from the rest. Remembering the order for T0, one can see that the order for FMax is similar except for RTL and IT, which are now relegated to the bottom from being at the top for the T0 values.

Vf and V2 as a Function of T0

Figures 16 – 19 illustrate an attempt to find a relationship between the wetting time T0 and the two SERA responses that were recorded, V2 and Vf. There is of course no plot for NG as gold has no oxides produced by normal means. There is also no plot for immersion tin because all but two data points have T0 values of 5 seconds – the time/force curves never crossed the zero force line.

Unfortunately little can be said from the graphs. The Vf data is either very noisy (bare copper) or show little change (reflowed tin/lead and OSP). The situation with the V2 data is no better as the data for bare copper, reflowed tin/lead and OSP show no discernable trends. Only the data for immersion silver suggests viable trends, somewhat tenuous for the V2 data, more probable for the Vf data. However, even here significant changes in Vf were only seen when T0 had passed the 4 second mark.

Overall it is somewhat disappointing to find that for the conditions used for the project that SERA is rather insensitive to the changes to the samples that were tested.

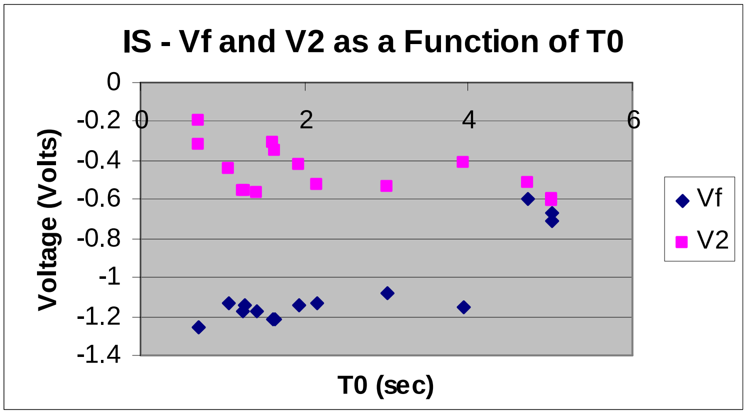

Figure 16 - Immersion Silver V2 and Vf as Functions of T0

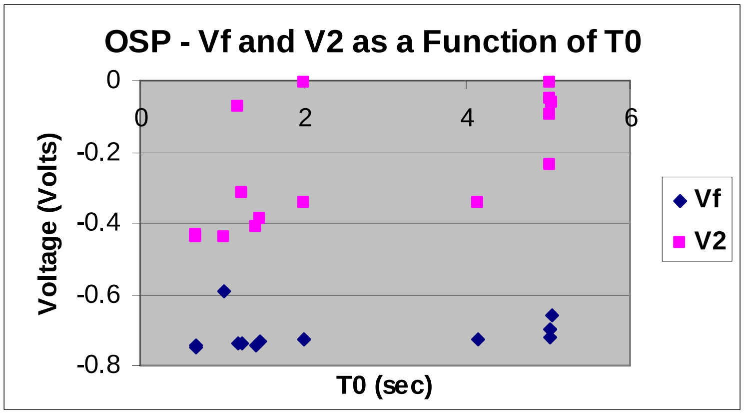

Figure 17 - OSP V2 and Vf as Functions of T0

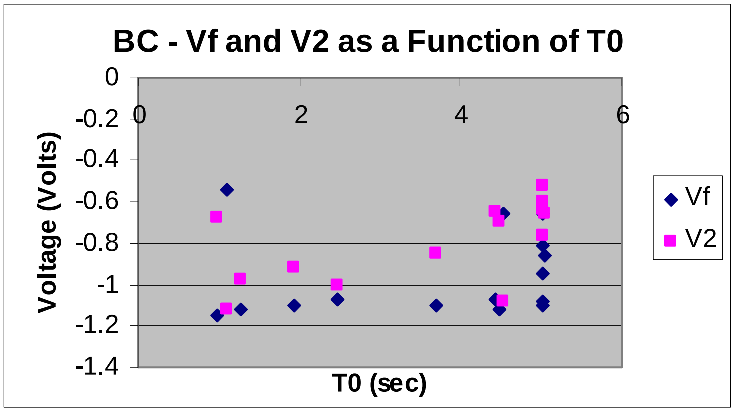

Figure 18 - Bare Copper V2 and Vf as Functions of T0

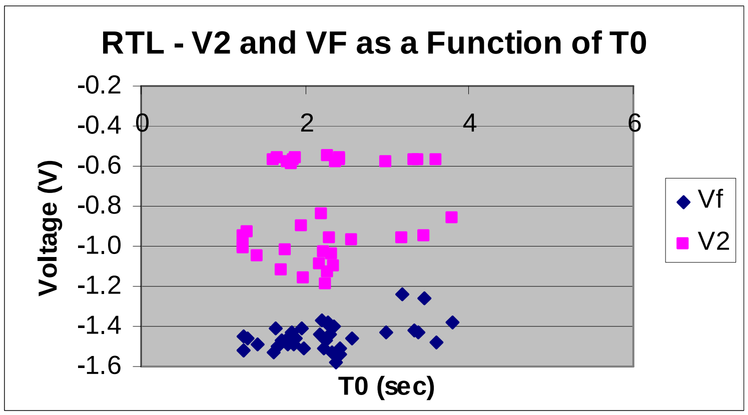

Figure 19 - Reflowed Tin/Lead V2 and Vf as Functions of T0

Vf as a Function of V2

There is little change for Vf as V2 changes for OSP. The data scatter for RTL is too large to draw any conclusions. The large number of V2 values at -0.6V would seem to suggest that tin/copper intermetallic was at the surface on many samples. There appears to a slight increase in Vf as V2 increases for IT and a decrease in Vf as V2 increases for IS. It is unclear whether the "bathtub" shape for the bare copper data is real or not. There are not enough data points.

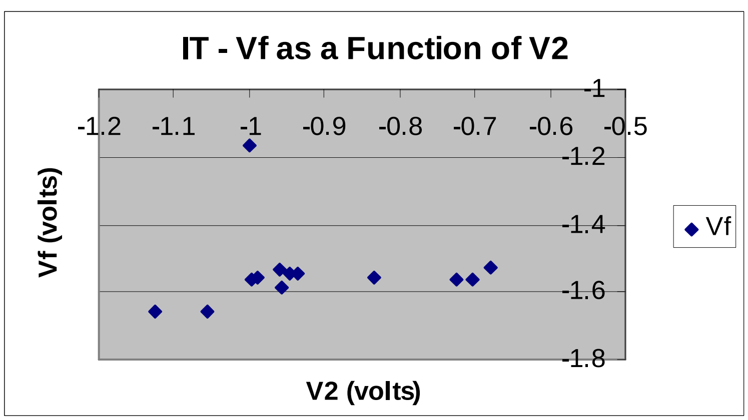

Figure 20 - Immersion Tin Vf as a Function of V2

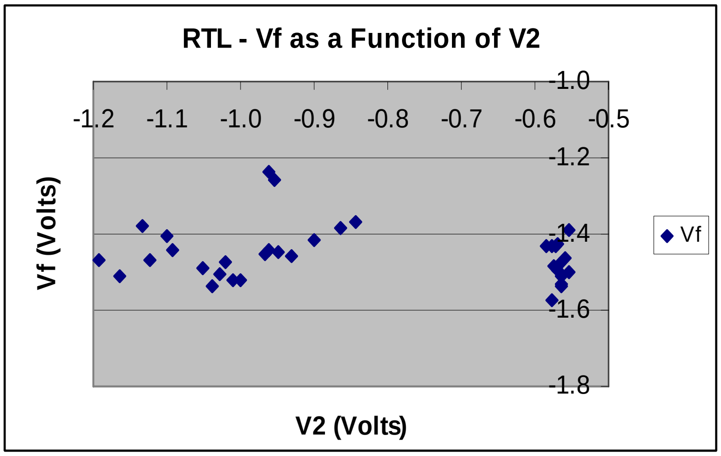

Figure 21 - Reflowed Tin/lead Vf as a Function of V2

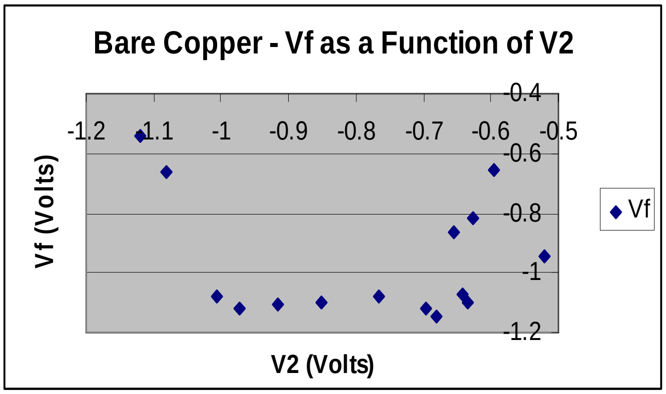

Figure 22 - Bare Copper Vf as a Function of V2

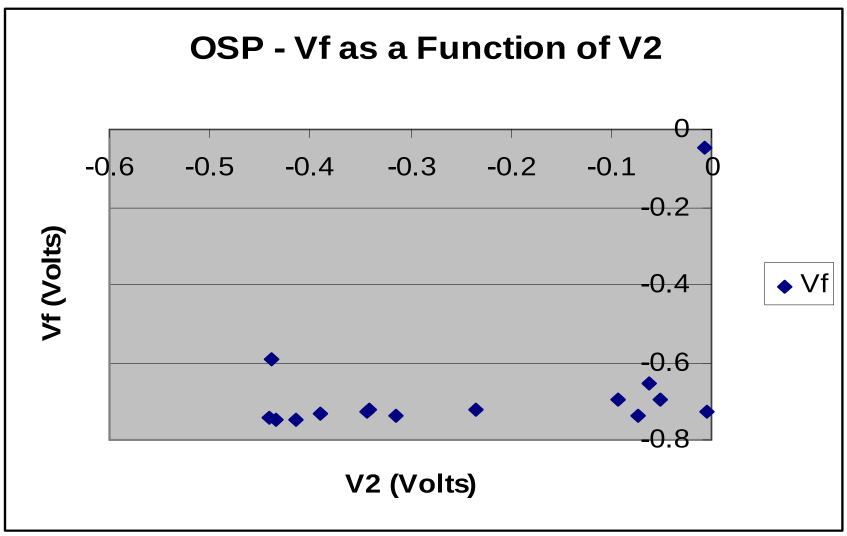

Figure 23 - OSP Vf as a Function of V2

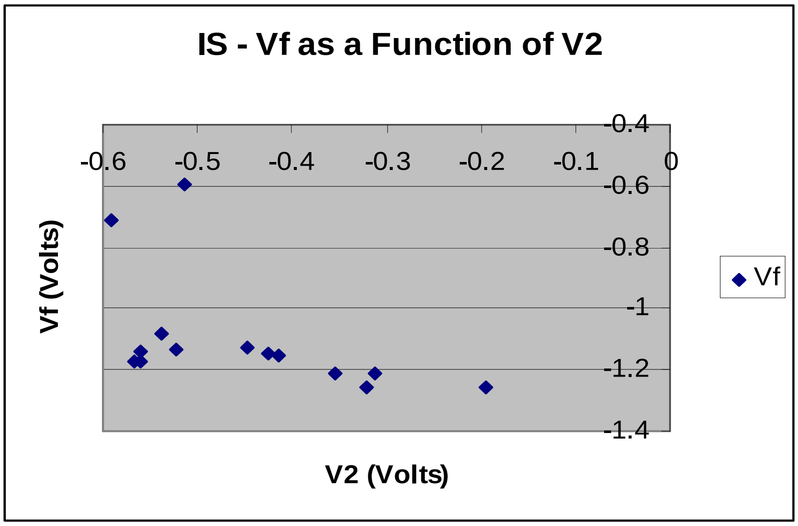

Figure 24 - Immersion Silver Vf as a Function of V2

Conclusions

Strong correlations between wetting times and wetting forces were found for all board finishes across the regimes used to condition the surface finishes tested. In this study T0 was used as the primary fixed variable to which the others were compared, but the work could have been done with T2/3FMax or FMax (normalized). Wetting times certainly seem to be related to the "nobleness" of the metal in question.

The reason why certain sets of data do not fit the curves drawn for some of the FMax = f(T0) is not known. Again the reflowed tin/lead and immersion tin are similar and the immersion silver and immersion gold are similar and OSP is in a third set. But the bare copper is not like the OSP, but more like the noble metals, with a straight line curve best describing the relations between T0 and FMax.

Surprisingly little useful information could be gleaned from the SERA data. SERA has proved very useful in the past so the reason for this with regards to this work cannot be explained at this time.

Much more work needs to be done to try and explain the chemistry and physics behind these results and to make the correlations more than just that.

References

1. Time, Temperature, and Humidity Stress of Final Board Finish Solderability Task Report - IPC Alternate Final Board Finishes Group - Committee 5-23-D, latest draft.
2. J-STD-002B, Solderability Tests for Component Leads, Lugs, Terminals and Wires, Produced by IPC and EIA associations STC and JEDEC, February 2003.
3. NG is used to represent ENIG in reference 1