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

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Abstract

The data from the IPC Alternate Finishes Task Group Report "Time, Temperature and Humidity Stress for Final Finish Board Solderability" has been analyzed in a greater depth than in the actual report or a subsequent paper[2]. Thermodynamically-based equations have been developed that are a better fit for the data than the intuitive ordering of the data in the report. Equations for the solderability results for the immersion silver, immersion tin, reflowed tin/lead, OSP and ENIG and the bare copper finishes studied in the IPC report are included here.

Introduction

Much empirical data has been collected, discussed and graphed in the last 50 years during the study of the solderability of various metal finishes on boards and components.[1-5] Those working in the electronics manufacturing field have a pretty good idea of how much time boards and parts can last in storage before the solderability degrades too much for them to be used. In many cases the degradation is caused by the growth of surface oxide coupled with the diffusion of underlying copper into the tin of the finish, leaving a copper/tin intermetallic highly susceptible to essentially non-reversible oxidation.[5]

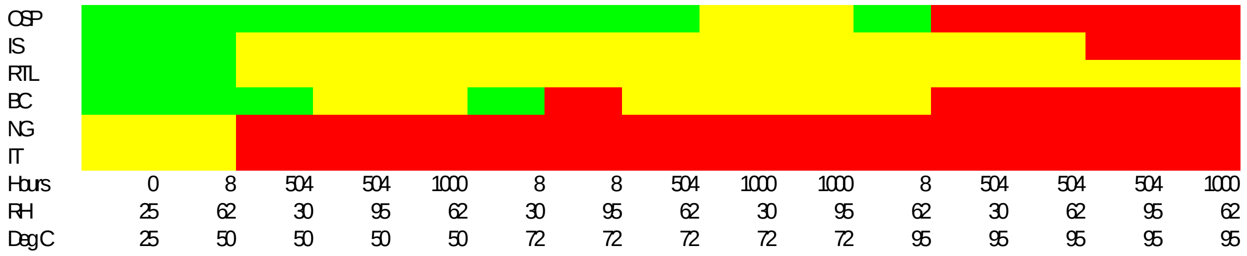
Equations already exist to determine the rate of oxide and intermetallic growth at constant temperatures[6]. From the components portion of the electronics industry, equations already exist for looking at their overall electrical reliability in terms of the application of constant humidity and temperatures conditions to cause accelerated aging. The former (humidity) is contained in the Peck Equation[7]:
Acceleration Factor = (elevated RH)/(RT RH)^n, where n commonly equals 2.66. No surprise to any chemist, temperature acceleration is described in term of the Arrhenius equation, as found in any physical chemistry textbook.[8]

Time was the other obvious variable to be considered in the IPC study. This also needs to be accounted for in any overall model. In the equation for the diffusion control of intermetallic growth it shows up with a power of one half.

This present exercise started out as a quest to provide a better understanding of the data collected in the IPC study. Different coupons were treated to various conditioning regimes and then tested for solderability in the IPC study. Specific test coupons were subjected to different temperatures and levels of humidity for various lengths of time. The effect of these conditions on the solderability of the coupons was measured using a wetting balance, dip and look and Sequential Electrochemical Reduction Analysis (SERA).[9] The final report presents the data and some analysis of the data. Results were sorted, intuitively in terms of temperature, time and humidity, in that order, for all data sets. The subsequent paper, published by the present author, detailed the presence or absence of relationships between the various measured parameters – Time to zero buoyancy, Time to 2/3F_{max}, maximum wetting force, and the SERA parameters V_2 and V_f.

Discussion

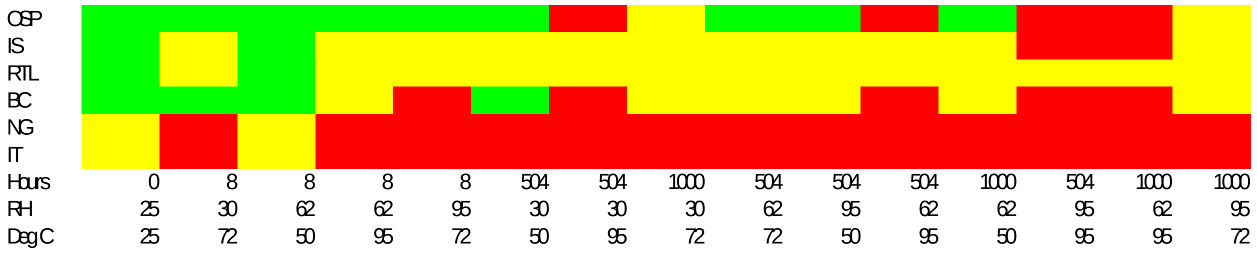
The summarized results of the data ordering in the IPC report mentioned above for the wetting balance data can be seen in **Figure 1**. Attempts to order the data in terms of the conditioning parameters – time, temperature and humidity can be done in three factorial (six) ways, but only the choice shown below provided the best order for the results seen. Solderability decreases in the order green to yellow to red.



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟥	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟨	🟨	🟨	🟥	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Hours	0	8	504	504	1000	8	8	504	1000	1000	8	504	504	504	1000
RH	25	62	30	95	62	30	95	62	30	95	62	30	62	95	62
Deg C	25	50	50	50	50	72	72	72	72	72	95	95	95	95	95

Figure 1 - Data ordering from IPC Final Finishes Report – Temperature/Time/Humidity

In this present work, the first attempt to come up with a better ordering scheme was made by multiplying all three conditioning parameters together. The result was even less successful. See **Figure 2**.



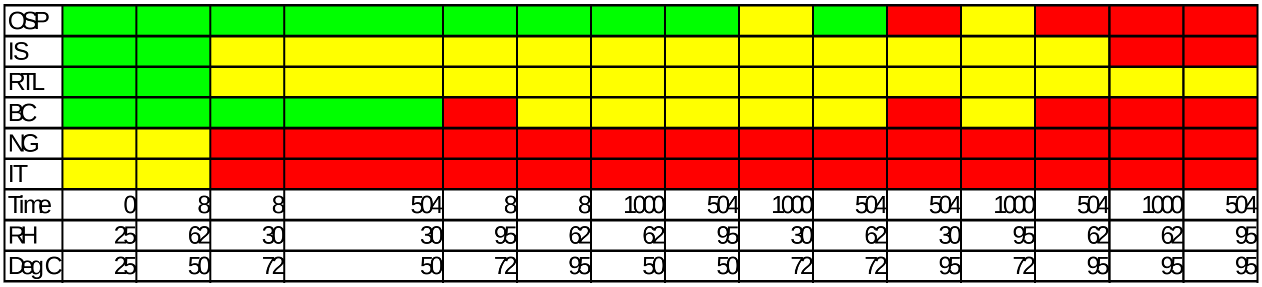
OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟥	🟩	🟥	🟥	🟨
IS	🟩	🟨	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥	🟨
RTL	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟨
NG	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Hours	0	8	8	8	8	504	504	1000	504	504	504	1000	504	1000	1000
RH	25	30	62	62	95	30	30	30	62	95	62	62	95	62	95
Deg C	25	72	50	95	72	50	95	72	72	50	95	50	95	95	72

Figure 2 - Ordering IPC Final Finishes Report Data in terms of Temperature*Time*Humidity

Using the Peck and Arrhenius equations discussed above in the introduction, the next phase involved trying to develop an equation that could be used to explain all of the data in thermodynamic/activation energy terms. This was done by brute force. No computer program was used to optimize the results. The starting point was: Acceleration = Time * (elevated RH/RT RH)$^{2.66}$* e-((Ea/R*T)*(1/RT - 1/T)).

Where;
Time is in seconds
2.66 is taken from reference **7**
Ea = activation energy = 0.7 eV, again from ref. **7**
R = gas constant 0.000086173 eV
T = temperature in degrees Kelvin

The best result that was obtained is shown in **Figure 3**:
Acceleration = Time$^{0.78}$ * (elevated RH/RT RH)$^{1.5}$ e-((Ea/R*T)*(1/RT - 1/T)).



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥	🟨	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟩	🟥	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Time	0	8	8	504	8	8	1000	504	1000	504	504	1000	504	1000	504
RH	25	62	30	30	95	62	62	95	30	62	30	95	62	62	95
Deg C	25	50	72	50	72	95	50	50	72	72	95	72	95	95	95

Figure 3 - Ordering data with one general thermodynamically-based equation

The next step was to try and determine equations for each finish, as the results would tend to indicate that different aging mechanisms/rates are most likely at work.
Using FMax data as a barometer, equations were built for the finishes RTL, IT and ENIG. The results were as follows:

RTL Accel. = Time* (elevated RH/RT RH)$^{0.55}$ e-((0.5/R*T)*(1/RT - 1/T))

IT Acceleration = Time$^{0.25}$* (elevated RH/RT RH) e-((1.0/R*T)*(1/RT - 1/T))

ENIG Accel = Time$^{0.25}$* (elevated RH/RT RH)$^{1.4}$ e-((0.75/R*T)*(1/RT - 1/T))

At this point the standardized Pareto charts for FMax in the IPC report were re-examined. The top three Pareto candles for each finish were identified and the approximate values were taken from the graphs. See **Table 1**.

Table 1 - Top Three Positive Results from Standardized Pareto Charts

RTL		Bare Cu		IAg		ISn		ENIG		OSP	
Time	22	Temp	10.7	Temp	40	Temp	12.3	Temp	11.4	Temp	65
Temp	17	RH	7.2	Temp^2	25	RH^2	9.5	RH	8.8	Time	44
RH^2	9.5	Temp^2	5	Temp*RH	22	RH	5	RH^2	8	Temp^2	32

Giving three "points" for a first place finish in importance in the Pareto charts, 2 for second and one for third, the following matrix was constructed (**Table 2**):

Table 2 - Assigning Point Values to the Pareto Factors

	Finish **Top 3 Pareto Factors**	**Points**		
	(first) -> (third)	**Time**	**Temp**	**RH**
RTL	Time, Temp, RH^2	3	2	1
IT	Temp, RH^2, RH	0	3	2+1
ENIG	Temp, RH, RH^2	0	3	2+1
OSP	Temp Time Temp^2	2	3+1	0
IAg	Temp, Temp^2, Temp*RH	0	3+2+1	1
Bare Cu	Temp, RH, Temp^2	0	3+1	2

It was then noticed that for the first three finishes, for which equations had been constructed, that there was some similarity between the point ratios with the exponents of the variables in the equations. This is shown in **Table 3.**

Table 3 - Comparisons of Pareto Points and Constructed Equation Exponents

	Points			Exponents		
	Time	**Temp**	**RH**	**Time**	**Temp**	**RH**
RTL	3	2	1	1	0.5	0.55
IT	0	3	3	0.25	1	1
ENIG	0	3	3	0.25	0.75	1.4

After noting this, the initial equations for the other three finishes were constructed using the points ratios as a starting place. The three equations that resulted, again after trial and error manipulation, were:

OSP Accel. = Time* (elevated RH/RT RH)$^{0.8}$ e-((0.8/R*T)*(1/RT - 1/T))

IAg Acceleration = Time$^{0.25}$* (elevated RH/RT RH)$^{0.5}$ e-((1.5/R*T)*(1/RT - 1/T))

Bare Cu Accel = Time$^{0.25}$* (elevated RH/RT RH)$^{0.875}$ e-((0.5/R*T)*(1/RT - 1/T))

The equations were constructed to give as close to a proper ordering of the condition sets shown in Figures 1-3 as possible. The points for each condition compared to the corresponding finished equation exponents are given below in **Table 4**.

Table 4 - Comparisons of Pareto Points and Corresponding Equation Exponents

Time

Points	Exponent	
RTL	3	1
IT	0	0.25
ENIG	0	0.25
OSP	2	1
IAg	0	0.25
Bare Cu	0	0.25

Temperature

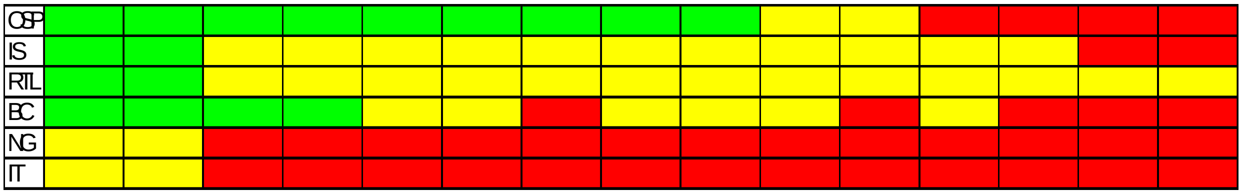
Points	Exponent	
RTL	2	0.5
IT	3	1
ENIG	3	0.75
OSP	4	0.8

IAg	6	1.5	Bare Cu	4	0.5

Humidity Points	Exponent	
RTL	1	0.55
IT	3	1
ENIG	3	1.4
OSP	0	0.8
IAg	1	0.5
Bare Cu	2	0.875

It can be seen that the match between the “points” and the final exponents used in the equations is somewhat weak, but using the points as a starting place was not an unreasonable idea.

Applying the equations to the “signal light” chart of the type shown in Figures 1-3 gives the result shown in **Figure 4**.



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Figure 4 - Signal Light Diagram for Wetting Balance Data Arranged Using Individual Equations for Each Final Finish

This chart shows even better alignment than the original chart. This is mainly because it takes into account the differences between the assorted finishes.

The equation for each finish was then applied to all the data sets (data sets labeled 1 to 15 on the X axis) for each finish. The results are compared with the corresponding figure from the IPC document for the F_{Max} values where the data sets were ordered by the intuitive ordering of temperature, time and then humidity. See **Figures 5 – 16**.

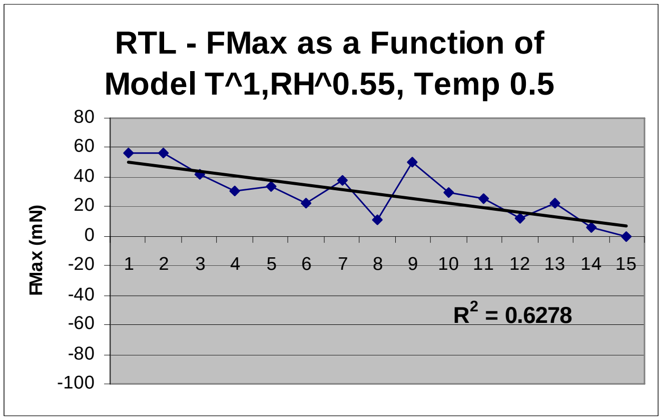

RTL - FMax as a Function of Model T^1,RH^0.55, Temp 0.5

Figure 5

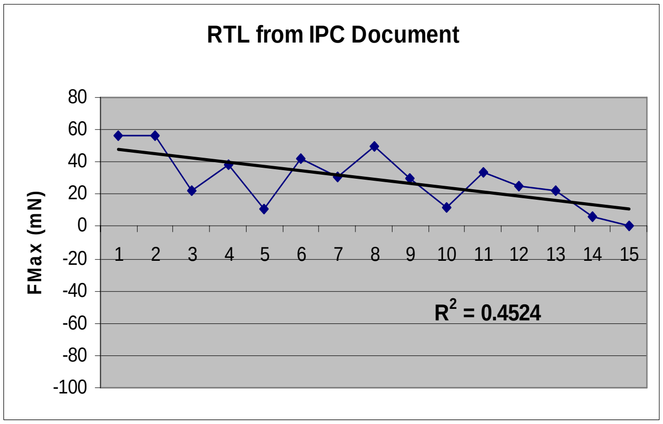

RTL from IPC Document

Figure 6

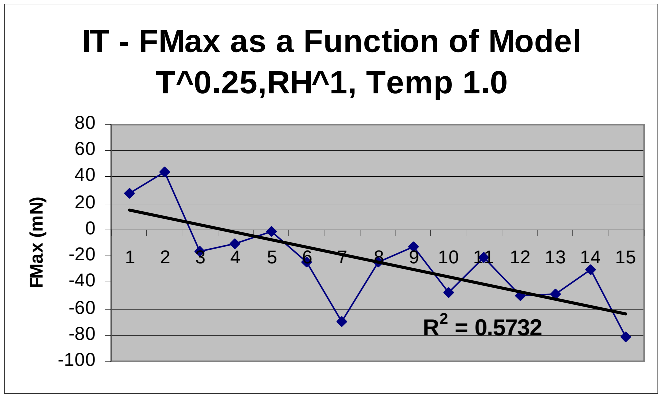

IT - FMax as a Function of Model T^0.25,RH^1, Temp 1.0

Figure 7

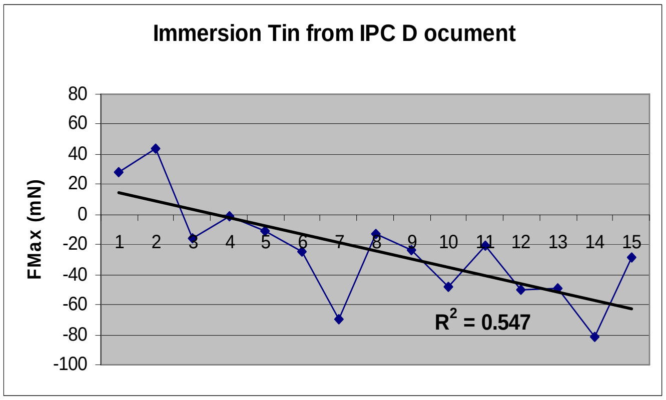

Immersion Tin from IPC D ocument

Figure 8

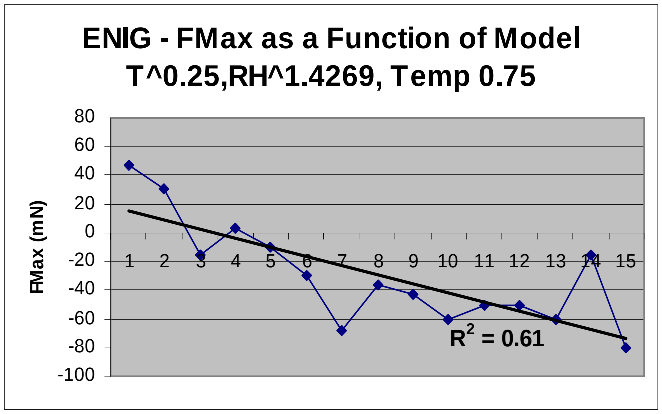

ENIG - FMax as a Function of Model T^0.25,RH^1.4269, Temp 0.75

Figure 9

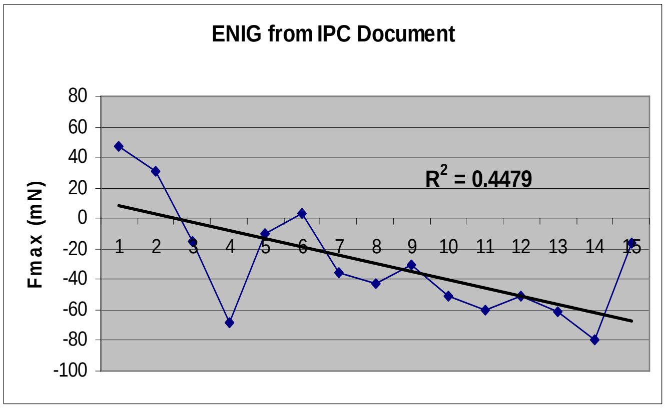

ENIG from IPC Document

Figure 10

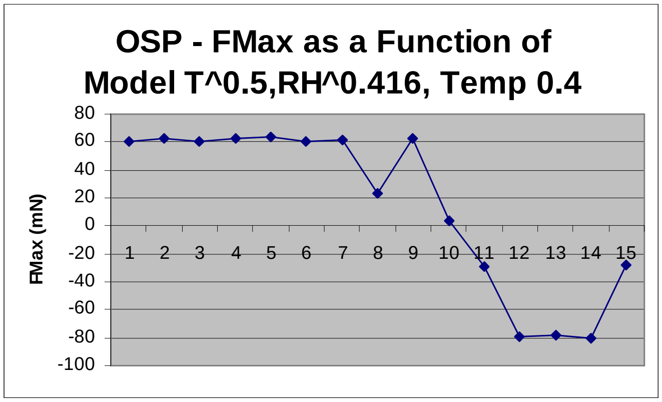


Figure 11

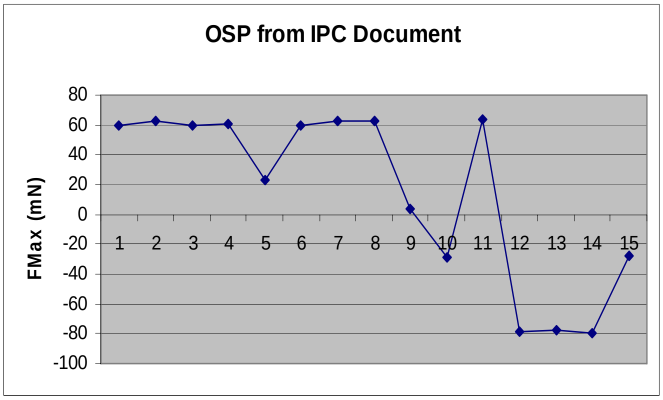


Figure 12

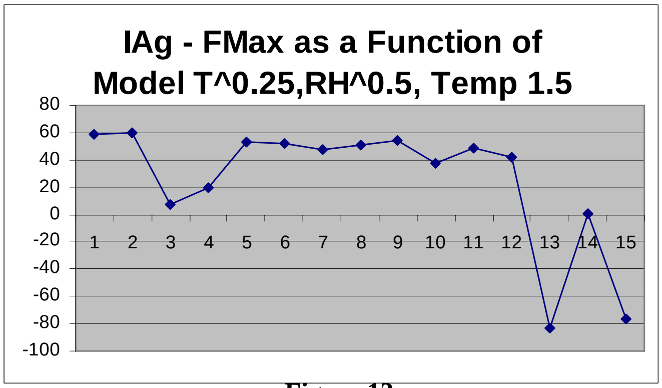


Figure 13

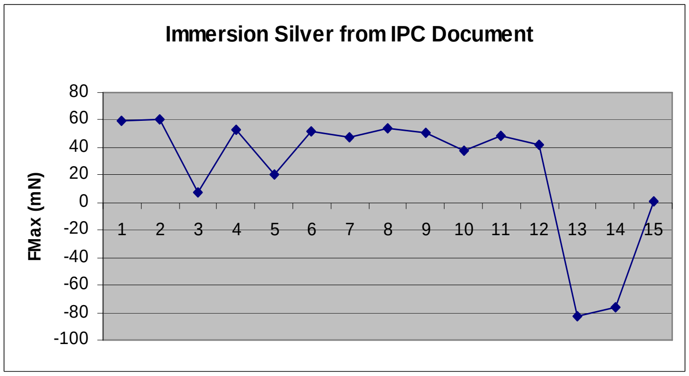


Figure 14

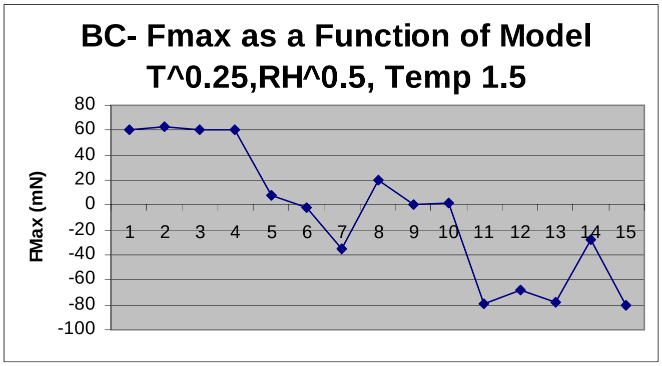


Figure 15

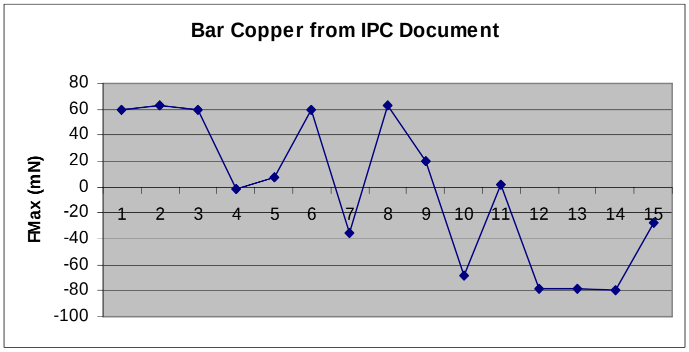
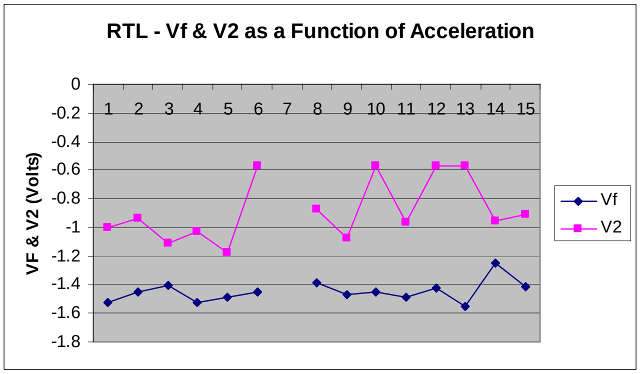
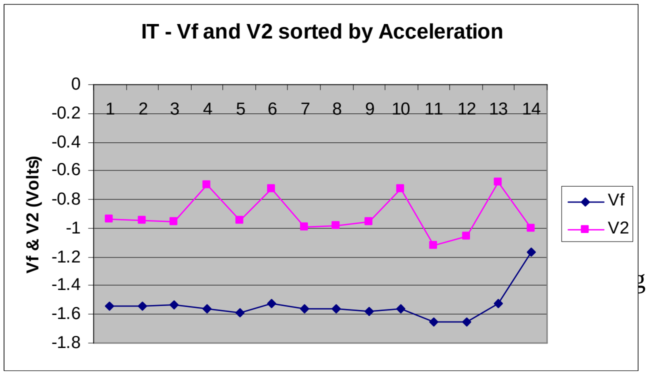


Figure 16

Figures 17 – 21 show similar results for applying the order calculated from the equations to the SERA V_f and V_2 results.





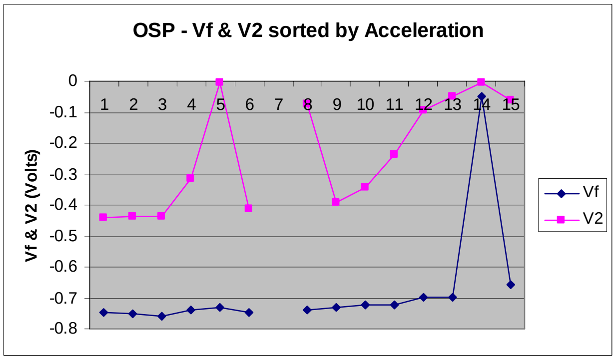


Figure 19 OSP V_f and V_2 Values Ordered Using Acceleration Equation

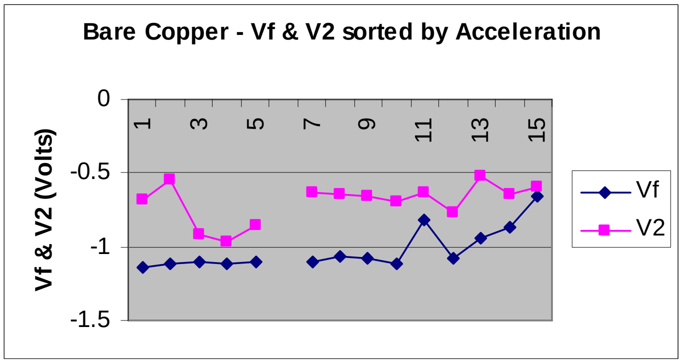


Figure 20 BC V_f and V_2 Values Ordered Using Acceleration Equation

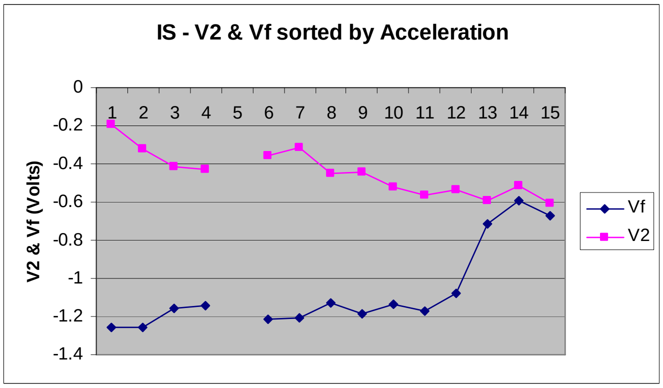


Figure 21 IS V_f and V_2 Values Ordered Using Acceleration Equation

Some observations can be made about the V_f and V_2 values that could not be made by just sorting the V_f and V_2 values on the basis of FMax.

Figure 17 shows that still nothing can be said about the RTL V_f and V_2 values. This is rather surprising, as SERA is often used successfully for examining tin/lead surfaces.

The immersion tin finish V_f and V_2 data are shown in **Figure 18**. The only difference to the above is that for the two most extreme conditioning regimes, 95/95/504 and 95/62/1000, V_f changes from around –1.6V towards –1.2V. This is a substantial change, however, is would be nice if earlier changes could be captured.

Figure 19 for OSP is much more interesting. For V_f there is a gradual but steady rise from –0.75 V to -0.65 V. It can be said with some confidence that point #14 (95/95/504) must be an error. For V_2 the change seems to be starting at about point number four or five. Again it is quite likely that the values plotted for point 4, 5 and 8 are in error.

Similar statements made for immersion tin can be made for the bare copper results of **Figure 20**.

SERA certainly seems well suited for immersion silver. There is a steady decrease in V_2 values for immersion silver from –0.2 to –0.6 Volts over the course of the different conditions examined. V_f values are less instructive and only show the upward curve for the last few values.

Conclusions

The original IPC Alternate Finishes data was sorted intuitively on the basis time, temperature and humidity, in that order. This work shows the thermodynamic basis for that and by the application of thermodynamically based equations provides a better ordering of the results for the individual finishes.

It would appear that a lot more work needs to be done to understand the results that can be derived from SERA work in this area.

The next stage would be for the electronics community to agree whether, T0, $T_{2/3Fmax}$, T_1, T_2, F_1, F_2, F_{max}, area under the curve or some other criteria be used as the ultimate pass/fail criteria for solderability testing. For example, is $T_1 = 2$ seconds and $T_2 = 5$ seconds? How long should the test be? If one researcher uses a total test time of 5 seconds and others use 10 seconds, then for curves that do not reach equilibrium plateau, but continue to rise over the course of the particular run, very different results will be calculated for $T_{2/3FMax}$ for a 5 second test versus 10 second test. Also, if forces are chosen as the basis for moving forward to apply to any set of equations, the forces must be presented in the form of force per unit wetted length to normalize the results. Consideration must also be given to thermal effects. Equations of the type presented in this paper might form the basis for the next step in the ultimate goal of developing a generalized set of equations for the solderability of all finishes.

References

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Introduction

Much empirical data has been collected, discussed and graphed in the last 50 years during the study of the solderability of various metal finishes on boards and components.[1-5] Those working in the electronics manufacturing field have a pretty good idea of how much time boards and parts can last in storage before the solderability degrades too much for them to be used. In many cases the degradation is caused by the growth of surface oxide coupled with the diffusion of underlying copper into the tin of the finish, leaving a copper/tin intermetallic highly susceptible to essentially non-reversible oxidation.[5]

Equations already exist to determine the rate of oxide and intermetallic growth at constant temperatures[6]. From the components portion of the electronics industry, equations already exist for looking at their overall electrical reliability in terms of the application of constant humidity and temperatures conditions to cause accelerated aging. The former (humidity) is contained in the Peck Equation[7]:

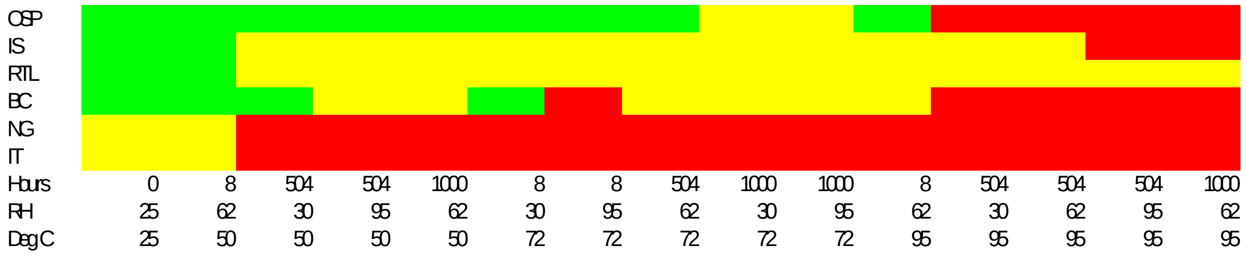
Acceleration Factor = (elevated RH)/(RT RH)^n, where n commonly equals 2.66. No surprise to any chemist, temperature acceleration is described in term of the Arrhenius equation, as found in any physical chemistry textbook.[8]

Time was the other obvious variable to be considered in the IPC study. This also needs to be accounted for in any overall model. In the equation for the diffusion control of intermetallic growth it shows up with a power of one half.

This present exercise started out as a quest to provide a better understanding of the data collected in the IPC study. Different coupons were treated to various conditioning regimes and then tested for solderability in the IPC study. Specific test coupons were subjected to different temperatures and levels of humidity for various lengths of time. The effect of these conditions on the solderability of the coupons was measured using a wetting balance, dip and look and Sequential Electrochemical Reduction Analysis (SERA).[9] The final report presents the data and some analysis of the data. Results were sorted, intuitively in terms of temperature, time and humidity, in that order, for all data sets. The subsequent paper, published by the present author, detailed the presence or absence of relationships between the various measured parameters – Time to zero buoyancy, Time to 2/3F_{max}, maximum wetting force, and the SERA parameters V_2 and V_f.

Discussion

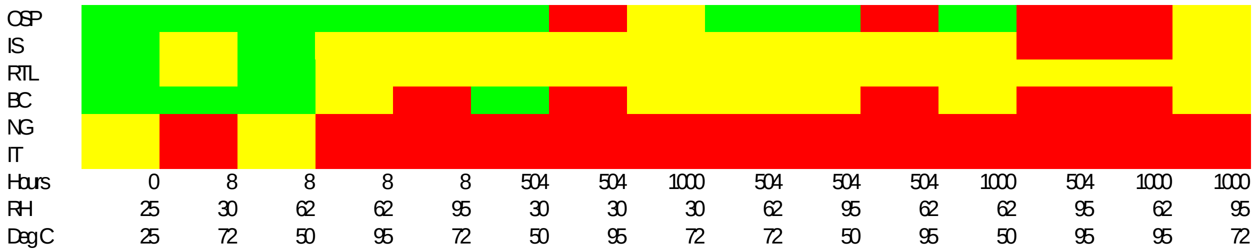
The summarized results of the data ordering in the IPC report mentioned above for the wetting balance data can be seen in **Figure 1**. Attempts to order the data in terms of the conditioning parameters – time, temperature and humidity can be done in three factorial (six) ways, but only the choice shown below provided the best order for the results seen. Solderability decreases in the order green to yellow to red.



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟥	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟨	🟨	🟨	🟥	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Hours	0	8	504	504	1000	8	8	504	1000	1000	8	504	504	504	1000
RH	25	62	30	95	62	30	95	62	30	95	62	30	62	95	62
Deg C	25	50	50	50	50	72	72	72	72	72	95	95	95	95	95

Figure 1 - Data ordering from IPC Final Finishes Report – Temperature/Time/Humidity

In this present work, the first attempt to come up with a better ordering scheme was made by multiplying all three conditioning parameters together. The result was even less successful. See **Figure 2**.



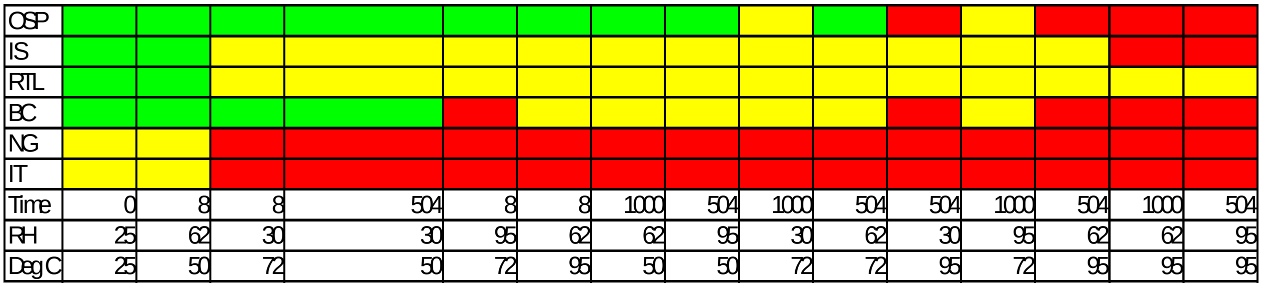
OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟥	🟩	🟥	🟥	🟨
IS	🟩	🟨	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥	🟨
RTL	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟨
NG	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Hours	0	8	8	8	8	504	504	1000	504	504	504	1000	504	1000	1000
RH	25	30	62	62	95	30	30	30	62	95	62	62	95	62	95
Deg C	25	72	50	95	72	50	95	72	72	50	95	50	95	95	72

Figure 2 - Ordering IPC Final Finishes Report Data in terms of Temperature*Time*Humidity

Using the Peck and Arrhenius equations discussed above in the introduction, the next phase involved trying to develop an equation that could be used to explain all of the data in thermodynamic/activation energy terms. This was done by brute force. No computer program was used to optimize the results. The starting point was: Acceleration = Time * (elevated RH/RT RH)$^{2.66}$* e-((Ea/R*T)*(1/RT - 1/T)).

Where;
Time is in seconds
2.66 is taken from reference **7**
Ea = activation energy = 0.7 eV, again from ref. **7**
R = gas constant 0.000086173 eV
T = temperature in degrees Kelvin

The best result that was obtained is shown in **Figure 3**:
Acceleration = Time$^{0.78}$ * (elevated RH/RT RH)$^{1.5}$ e-((Ea/R*T)*(1/RT - 1/T)).



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥	🟨	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟩	🟥	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Time	0	8	8	504	8	8	1000	504	1000	504	504	1000	504	1000	504
RH	25	62	30	30	95	62	62	95	30	62	30	95	62	62	95
Deg C	25	50	72	50	72	95	50	50	72	72	95	72	95	95	95

Figure 3 - Ordering data with one general thermodynamically-based equation

The next step was to try and determine equations for each finish, as the results would tend to indicate that different aging mechanisms/rates are most likely at work.
Using FMax data as a barometer, equations were built for the finishes RTL, IT and ENIG. The results were as follows:

RTL Accel. = Time* (elevated RH/RT RH)$^{0.55}$ e-((0.5/R*T)*(1/RT - 1/T))

IT Acceleration = Time$^{0.25}$* (elevated RH/RT RH) e-((1.0/R*T)*(1/RT - 1/T))

ENIG Accel = Time$^{0.25}$* (elevated RH/RT RH)$^{1.4}$ e-((0.75/R*T)*(1/RT - 1/T))

At this point the standardized Pareto charts for FMax in the IPC report were re-examined. The top three Pareto candles for each finish were identified and the approximate values were taken from the graphs. See **Table 1**.

Table 1 - Top Three Positive Results from Standardized Pareto Charts

RTL		**Bare Cu**		**IAg**		**ISn**		**ENIG**		**OSP**	
Time	22	Temp	10.7	Temp	40	Temp	12.3	Temp	11.4	Temp	65
Temp	17	RH	7.2	Temp^2	25	RH^2	9.5	RH	8.8	Time	44
RH^2	9.5	Temp^2	5	Temp*RH	22	RH	5	RH^2	8	Temp^2	32

Giving three "points" for a first place finish in importance in the Pareto charts, 2 for second and one for third, the following matrix was constructed (**Table 2**):

Table 2 - Assigning Point Values to the Pareto Factors

Finish	**Top 3 Pareto Factors**	**Points**		
	(first) -> (third)	**Time**	**Temp**	**RH**
RTL	Time, Temp, RH^2	3	2	1
IT	Temp, RH^2, RH	0	3	2+1
ENIG	Temp, RH, RH^2	0	3	2+1
OSP	Temp Time Temp^2	2	3+1	0
IAg	Temp, Temp^2, Temp*RH	0	3+2+1	1
Bare Cu	Temp, RH, Temp^2	0	3+1	2

It was then noticed that for the first three finishes, for which equations had been constructed, that there was some similarity between the point ratios with the exponents of the variables in the equations. This is shown in **Table 3.**

Table 3 - Comparisons of Pareto Points and Constructed Equation Exponents

	Points			Exponents		
	Time	**Temp**	**RH**	**Time**	**Temp**	**RH**
RTL	3	2	1	1	0.5	0.55
IT	0	3	3	0.25	1	1
ENIG	0	3	3	0.25	0.75	1.4

After noting this, the initial equations for the other three finishes were constructed using the points ratios as a starting place. The three equations that resulted, again after trial and error manipulation, were:

OSP Accel. = Time* (elevated RH/RT RH)$^{0.8}$ e-((0.8/R*T)*(1/RT - 1/T))

IAg Acceleration = Time$^{0.25}$* (elevated RH/RT RH)$^{0.5}$ e-((1.5/R*T)*(1/RT - 1/T))

Bare Cu Accel = Time$^{0.25}$* (elevated RH/RT RH)$^{0.875}$ e-((0.5/R*T)*(1/RT - 1/T))

The equations were constructed to give as close to a proper ordering of the condition sets shown in Figures 1-3 as possible. The points for each condition compared to the corresponding finished equation exponents are given below in **Table 4**.

Table 4 - Comparisons of Pareto Points and Corresponding Equation Exponents

Time		
Points	Exponent	
RTL	3	1
IT	0	0.25
ENIG	0	0.25
OSP	2	1
IAg	0	0.25
Bare Cu	0	0.25

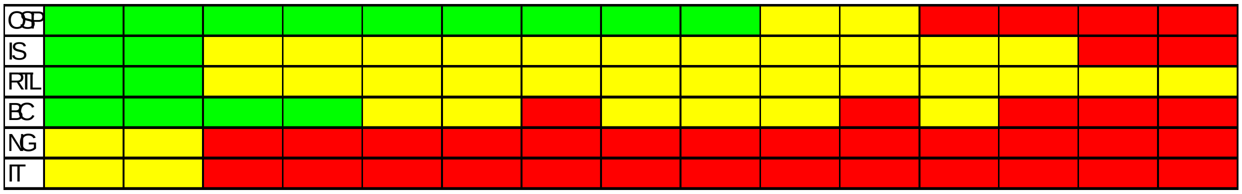
Temperature		
Points	Exponent	
RTL	2	0.5
IT	3	1
ENIG	3	0.75
OSP	4	0.8

IAg	6	1.5	Bare Cu	4	0.5

Humidity Points	Exponent	
RTL	1	0.55
IT	3	1
ENIG	3	1.4
OSP	0	0.8
IAg	1	0.5
Bare Cu	2	0.875

It can be seen that the match between the “points” and the final exponents used in the equations is somewhat weak, but using the points as a starting place was not an unreasonable idea.

Applying the equations to the “signal light” chart of the type shown in Figures 1-3 gives the result shown in **Figure 4**.



OSP	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟥
IS	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥
RTL	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
BC	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟥
NG	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
IT	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Figure 4 - Signal Light Diagram for Wetting Balance Data Arranged Using Individual Equations for Each Final Finish

This chart shows even better alignment than the original chart. This is mainly because it takes into account the differences between the assorted finishes.

The equation for each finish was then applied to all the data sets (data sets labeled 1 to 15 on the X axis) for each finish. The results are compared with the corresponding figure from the IPC document for the F_{Max} values where the data sets were ordered by the intuitive ordering of temperature, time and then humidity. See **Figures 5 – 16**.

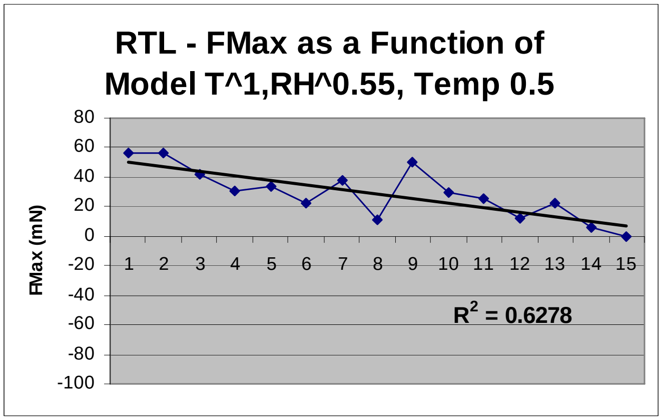


Figure 5

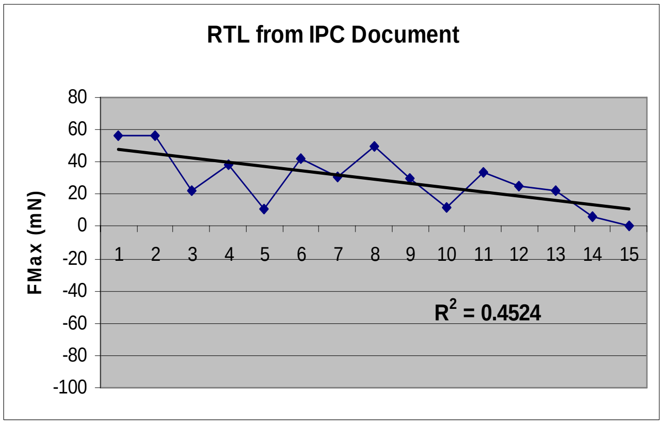


Figure 6

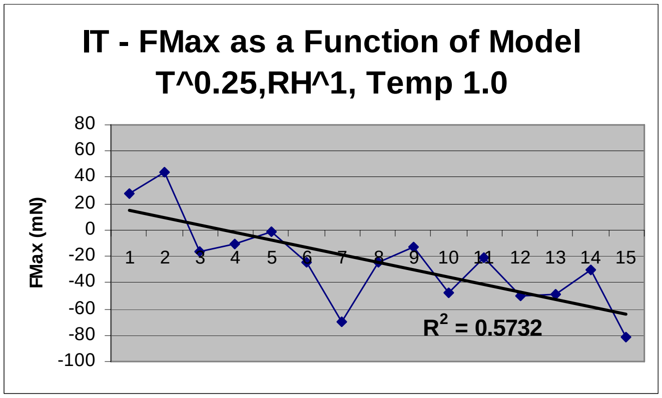


Figure 7

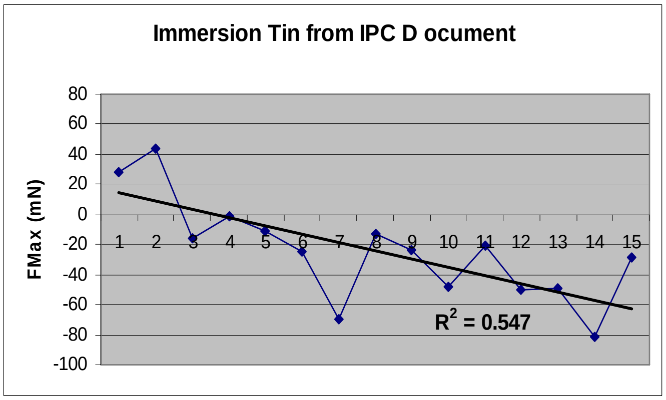


Figure 8

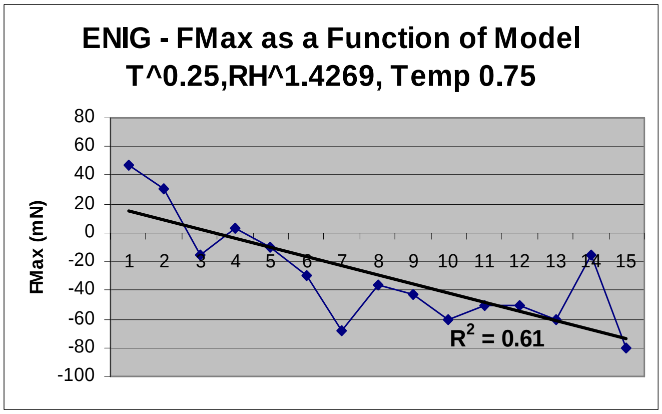


Figure 9

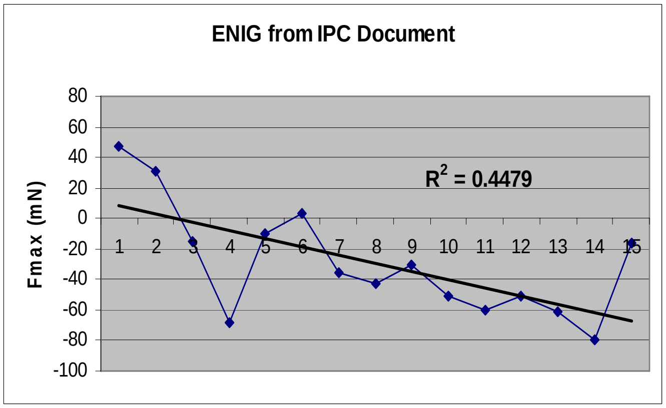
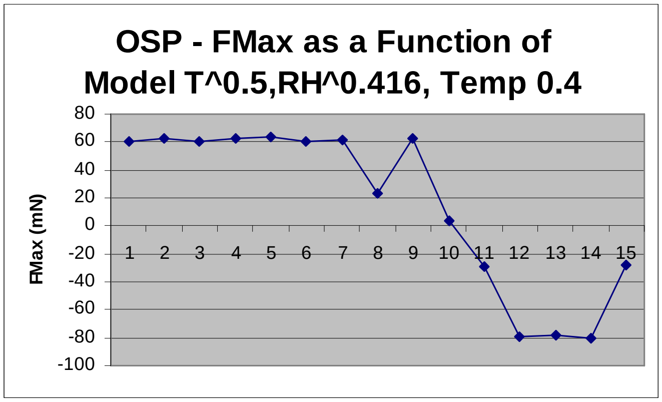


Figure 10



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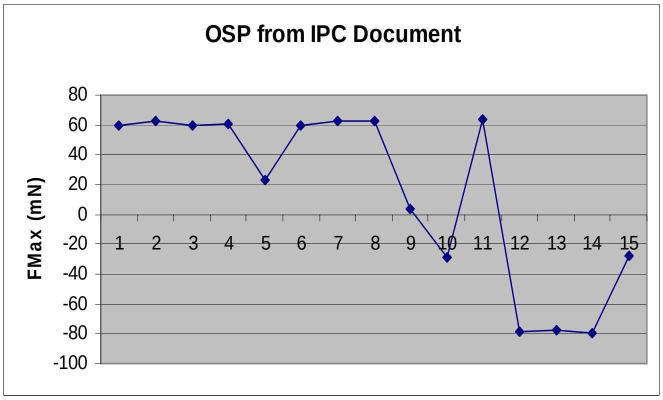

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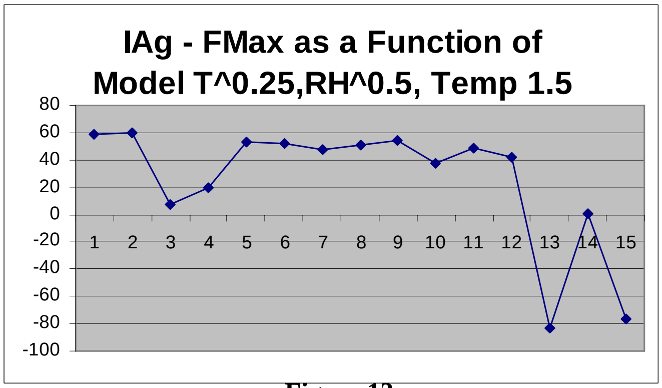


Figure 13

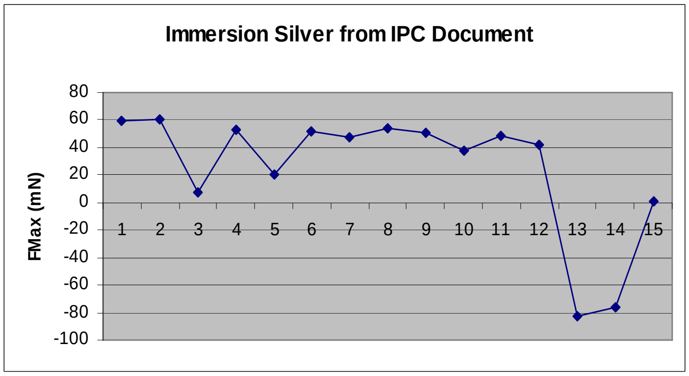


Figure 14

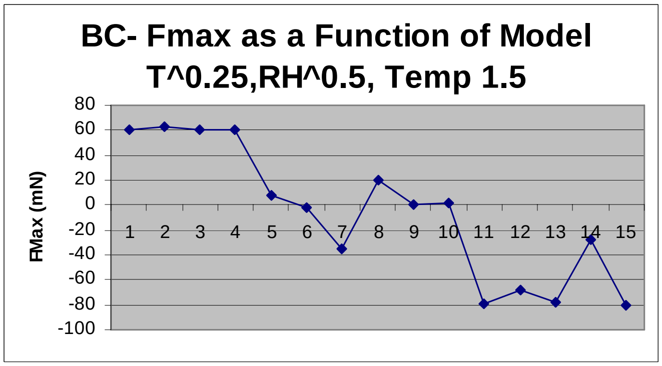


Figure 15

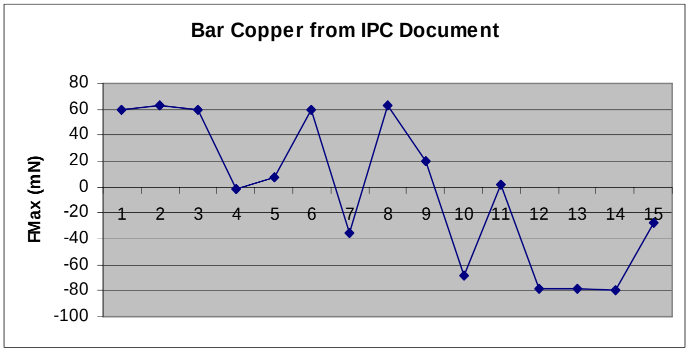
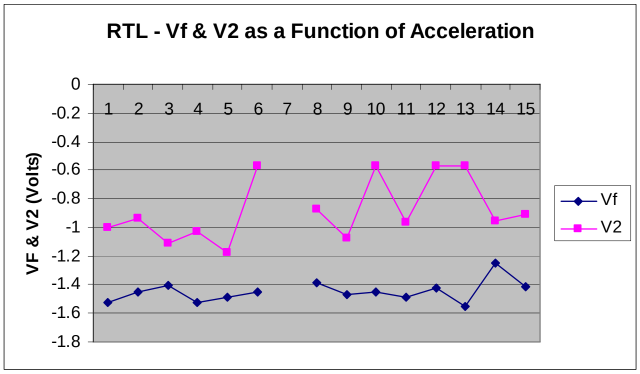
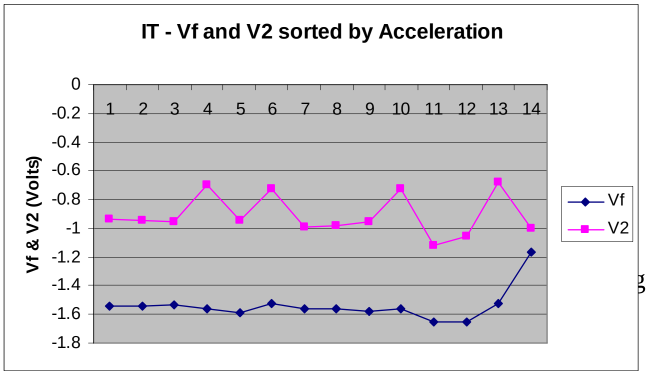
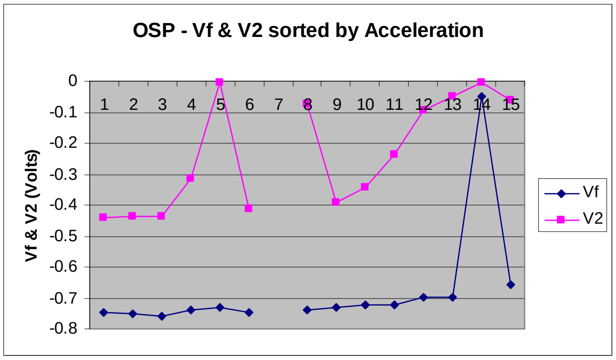


Figure 16

Figures 17 – 21 show similar results for applying the order calculated from the equations to the SERA V_f and V_2 results.







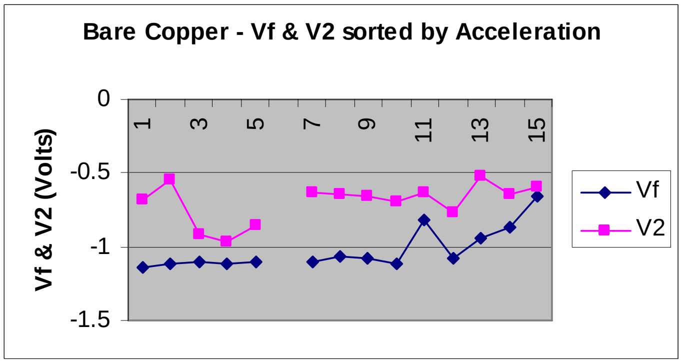


Figure 19 OSP V_f and V_2 Values Ordered Using Acceleration Equation

Figure 20 BC V_f and V_2 Values Ordered Using Acceleration Equation

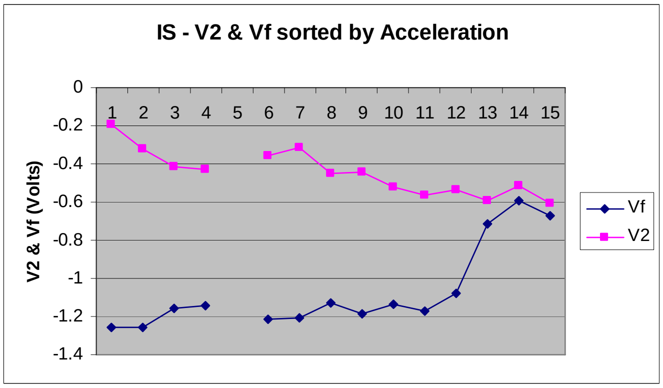


Figure 21 IS V_f and V_2 Values Ordered Using Acceleration Equation

Some observations can be made about the V_f and V_2 values that could not be made by just sorting the V_f and V_2 values on the basis of FMax.

Figure 17 shows that still nothing can be said about the RTL V_f and V_2 values. This is rather surprising, as SERA is often used successfully for examining tin/lead surfaces.

The immersion tin finish V_f and V_2 data are shown in **Figure 18**. The only difference to the above is that for the two most extreme conditioning regimes, 95/95/504 and 95/62/1000, V_f changes from around –1.6V towards –1.2V. This is a substantial change, however, is would be nice if earlier changes could be captured.

Figure 19 for OSP is much more interesting. For V_f there is a gradual but steady rise from –0.75 V to -0.65 V. It can be said with some confidence that point #14 (95/95/504) must be an error. For V_2 the change seems to be starting at about point number four or five. Again it is quite likely that the values plotted for point 4, 5 and 8 are in error.

Similar statements made for immersion tin can be made for the bare copper results of **Figure 20**.

SERA certainly seems well suited for immersion silver. There is a steady decrease in V_2 values for immersion silver from –0.2 to –0.6 Volts over the course of the different conditions examined. V_f values are less instructive and only show the upward curve for the last few values.

Conclusions

The original IPC Alternate Finishes data was sorted intuitively on the basis time, temperature and humidity, in that order. This work shows the thermodynamic basis for that and by the application of thermodynamically based equations provides a better ordering of the results for the individual finishes.

It would appear that a lot more work needs to be done to understand the results that can be derived from SERA work in this area.

The next stage would be for the electronics community to agree whether, T0, $T_{2/3Fmax}$, T_1, T_2, F_1, F_2, F_{max}, area under the curve or some other criteria be used as the ultimate pass/fail criteria for solderability testing. For example, is T_1 = 2 seconds and T_2 = 5 seconds? How long should the test be? If one researcher uses a total test time of 5 seconds and others use 10 seconds, then for curves that do not reach equilibrium plateau, but continue to rise over the course of the particular run, very different results will be calculated for $T_{2/3FMax}$ for a 5 second test versus 10 second test. Also, if forces are chosen as the basis for moving forward to apply to any set of equations, the forces must be presented in the form of force per unit wetted length to normalize the results. Consideration must also be given to thermal effects. Equations of the type presented in this paper might form the basis for the next step in the ultimate goal of developing a generalized set of equations for the solderability of all finishes.

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