The Effect of Testing a Copper Wire and a Copper Wire Coated with SnPb Solder using a Wetting Balance Machine

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Abstract— **A copper surface chemically passivated using some form of flux has been suggested as providing samples of different but reproducible degrees of solderability. The importance of closely controlling the preparation, and cleaning of the copper to obtain reproducible solderability is of high importance to ensure accurate and repeatable results when using the Wetting Balance Machine. After completing a capability study of the Wetting Balance machine prior to conducting any experiments, 20mm lengths of copper wire were used to assess the effect of soldering directly onto a copper wire surface compared with soldering onto a copper wire surface coated with tin/lead (SnPb) solder paying particular attention to the responses Fmax, maximum force reached during the test, TFmax, time to reach maximum force, T2/3 Fmax, time to reach two thirds of maximum force, Tb, time to reach buoyancy, and finally Ta, Time to reach the zero line of the x-axis. For the benefit of this investigation, 20mm lengths of the same reel of 0.9mm diameter insulated copper wire were used in order to minimise as much as possible any variances. For each 20mm length of copper wire used, an initial dip of the specimen into the solder bath, calculating the aforementioned responses, was followed by a second dip using the same initial copper wire but this time it had a coating of tin/lead solder from the first dip and again the relevant responses calculated using the Wetting Balance machine. A comparison of each response was done to compare the first dip with on a Cu surface and the second dip with the SnPb coating in order to assess the effect of thermal conduction.**

I. Introduction

Before conducting any experiments on the Wetting Balance machine an indebt capability study was concluded in order to assess the machine's performance paying particular attention to its ability to provide accurate and repeatable results, while gaining a complete understanding of the machines capability. It was also vitally important to understand and minimise, as much as possible, any external influences other than the machine operation, which may affect the accuracy of the results. A systematic examination of the machine would ensure that the quality features and characteristics required could be experimented under statistically controlled conditions. As well as the calibration check of the Wetting Balance machine, it was also taken into account the effect external influences such as vibrations from other equipment within the vicinity of the Wetting Balance machine had on the accuracy of the results. [1]

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Because of the importance in quality assurance of solderability testing of components and printed circuit boards, a large number of test procedures have been developed. Each type of test provides one or more criteria upon which the solderability of a component (and hence the batch of which it is representative) can be accepted or rejected. In order to quantify the tests and enable direct comparisons to be made, standard reference surfaces must be tunable to fall within the range encountered in practice, such that components with solderability worse than the standard are rejected while those better than the standard are accepted, for all test procedures. A copper surface chemically passivated using some form of flux has been suggested as providing samples of different but reproducible degrees of solderability. The importance of controlling the preparation and fluxing of each sample in order to obtain reproducibility must be adhered to. [2]

Copper has a red, orange or brown colour because a thin layer of tarnish (including oxides) gradually forms on its surface when gases (especially oxygen) in the air react with it. It is a good conductor of heat and electricity. To investigate further the conduction of heat and also the effect of testing a copper wire surface for solderability using a MUST II Wetting Balance machine, test copper wire samples of 20mm lengths were used. 20mm lengths were the minimum length to which the clip on the machine could grip securely.

II. OBJECTIVES

The main objectives of this investigation were;

- Determine the maximum and minimum results for Fmax, TFmax, Tb, and Ta for;
  - Copper wire surface
  - Copper wire surface coated with SnPb
- Determine the standard deviation for each of the aforementioned responses.
- Graphically represent the results for the responses using Minitab.

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III. PROCEDURE

The capability study was conducted on the current Wetting Balance machines performance using a 0.9mm copper wire. In total seventy repeated measurements were conducted using the settings in Table 1. Thirty-five readings for Copper wire surface and thirty-five readings for copper wire surface coated with SnPb and flux.

The following procedure was carried out to determine the machine's capability;

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- 20mm lengths of 0.9mm diameter copper wire were used. The reason for using the copper wire instead of component leads was to minimise any variation in the leads ability to solder as a result of poor component torage and shelf life. The 20mm lengths were taken from the same reel of insulated wire directly before use. For each of the seventy measurements one length of 20mm copper wire was used twice.
- The settings in Table 1 were entered into the Wetting Balance machine. These settings were recommended by the Wetting Balance machine manufacturer.
- The solder used in the bath was tin/lead (SnPb), a standard alloy used throughout the industry for soldering electronic components.
- The flux used for the test was a standard qualified production flux used within many electronics manufacturing companies.
- Using gloves, the 20mm lengths of copper wire were mounted onto the Wetting Balance holder using clip no. 18. This is the recommended clip type for wires.
- The program was enabled and each step was automatically prompted by the machine, i.e. flux applied, dross removed from solder bath surface, copper wire change etc.
- An initial dip of the Copper wire into the solder bath was completed and the results for Fmax, TFmax, Tb, and Ta were recorded. After this dip the copper wire was coated with SnPb.
- Using the same length of Copper (now coated with SnPb) a further dip was initiated into the solder bath. Again the results for Fmax, TFmax, Tb, and Ta were recorded.
- The same procedure was completed for all thirty-five lengths of copper wire. Each result was automatically recorded by the machine and presented in a graph format. The software on the Wetting Balance machine was only capable of recording fifteen measurements on one graph so the above procedure was repeated until the seventy measurements were complete. Appendix 1 shows a typical wetting balance graph for 14 readings – 7 readings first dip and 7 readings second dip.

Table 1 Main Settings used on the Wetting Balance Machine [3]

Variable	Settings
Immersion Speed	20mm/sec
Immersion Depth	4mm
Dwell Time	5 seconds
Solder Temperature	235^{0}C

The seventy recorded results using the settings in Table 1 were analysed using the Minitab software for the responses;

- Fmax (maximum force reached during the test)
- Tb (time to reach buoyancy)
- TFmax (time to reach maximum force, TFmax)
- Ta (time to cross the zero line (x-axis) on the Wetting Balance Graph.

IV. ANALYSES OF RESULTS

Maximum Force, Fmax

In order to determine the theoretical Fmax result using a 0.9mm diameter copper wire the following formula was used;

Fmax = [0.4P – 0.08V]………. [4]

Where, 0.4 is the surface tension (γ) of solder; P is the circumference of the wire; 0.08 is the density (ρ) of the solder (Pb); V is the immersed volume and Immersion depth of 4mm used from Table 1.

$P = 2\pi r \Rightarrow P = 2 \times \pi \times 0.45 \Rightarrow P = 2.8274mm$

$0.4P = 0.4 \times 2.8274 \Rightarrow 0.4P = 1.1309$

$V = (\pi d2/ 4) \times 4$

$V = (\pi (0.9)2 / 4) \times 4 = 2.544mm3$

$0.08V = 0.08 \times 2.544 = 0.20357$

$F = [1.1309 – 0.20357] \Rightarrow F = 0.9274mN$

Figure 1 Line Plot of Fmax First Dip vs. Fmax Second Dip

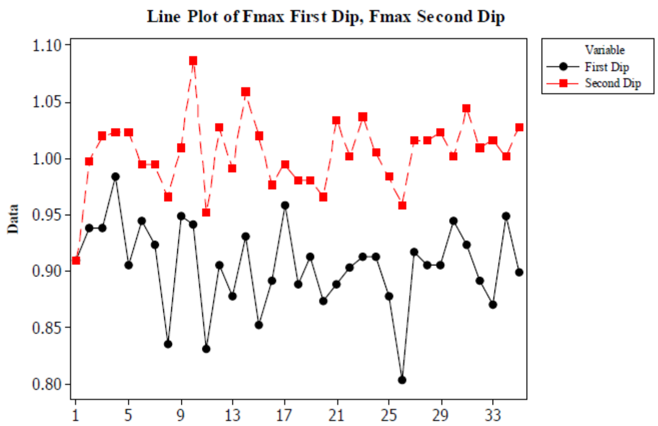

Figure 1 above represents a line graph generated by Minitab for Fmax values automatically calculated using the Wetting Balance machine for the first and second dip measurements of thirty-five copper wires. It is clearly evident that the first Dip of the copper wire surface into the bath of solder presents maximum forces much less than the second dip. The standard deviations differ for both dips between the thirty five readings, first Dip (0.04) and second Dip (0.03). A maximum reading of 0.98mN and a minimum of 0.80mN for first dip (average 0.91mN) and maximum 1.09mN and minimum 0.91mN for the second dip (average 1mN) were achieved. The difference between first and second dip of the copper solder wire highlight the thermal conductivity of copper and this adds to the fact the testing using a wetting balance machine for solderability of a copper wire surface will not give accurate readings because of this variation.

Time to Buoyancy, Tb

The recognised standard time to buoyancy is less than 0.6 seconds [3]. Figure 2 below is a representation showing the Tb results from the same thirty five copper wires used throughout this investigation. Again the evidence is visually portrayed that the second dip provides much more stable results. All of the thirty five readings for the first dip surpass the standard requirement of less than 0.6 seconds but for the first dip results approximately 83% failed.

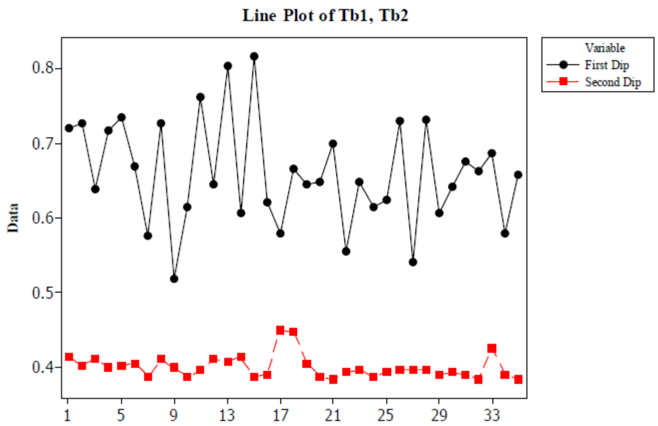

Figure 2 Line Plot of Tb First Dip vs. Fmax Second Dip

A maximum and minimum of 0.82 and 0.52 seconds respectively for first dip and a maximum and minimum of 0.45 and 0.38 seconds respectively for the second dip were achieved. The standard deviation was calculated by Minitab to be 0.07 seconds for first dip and 0.02 seconds for second dip.

Time to reach maximum force, TFmax.

The time for the solder to reach its maximum force for the first and second dip is graphically shown in Figure 3 below. A maximum value 2.84 seconds, a minimum 1.61 and a standard deviation of 0.27 seconds was calculated for the first dip results. The second dip line illustrates almost a linear line except for two readings which may be as a result of an external noise or the solderability of the copper wires. For the benefit of calculating the standard deviation and maximum readings for the seconds dip, these two outliers were removed and the results were maximum 0.72 seconds, minimum 0.6 seconds and standard deviation 0.02 seconds (1.36 maximum and standard deviation of 0.16 seconds if outliers included).

Time to cross zero line (x-axis), Ta

Similar to the Tb response, Ta also has a requirement to be achieved during the testing. Less than 1 second is the standard required. Figure 4 below present the results generated by Minitab.

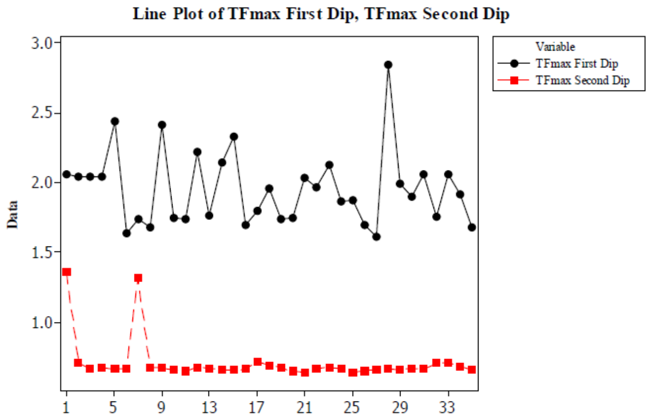

Figure 3 Line Plot of TFmax First Dip vs. TFmax Second Dip

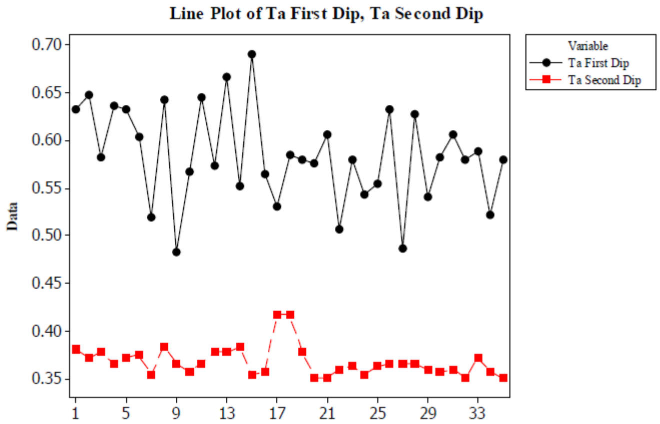

Figure 4 Line Plot of Ta First Dip vs. Ta Second Dip

Again similar to the previous graphs seen so far there is a significant difference between the first and second dip results. For Ta, a minimum of 0.48 seconds, a maximum of 0.69 seconds and a standard deviation of 0.05 seconds were achieved for the first dip. For the second dip, a minimum of 0.35 seconds, a maximum of 0.42 seconds and a standard deviation of 0.02 seconds were achieved.

V. SUMMARY

The main focus of the investigation in the paper was to compare the affect of testing a copper wire surface using a Wetting Balance machine to testing that same piece of copper wire coated with tin-lead solder. Table 2 is a summary of the results achieved for Fmax, Tb, TFmax and Ta using two dips.

Table 2 Summary table of results

	First Dip			Second Dip		
Response	Std. Dev.	Maximum	Minimum	Std. Dev.	Maximum	Minimum
Fmax	0.04	0.98	1.09	0.03	0.80	0.91
Tb	0.07	0.82	0.52	0.02	0.45	0.38
TFmax	0.27	2.84	1.61	0.72	0.60	0.02
Ta	0.05	0.69	0.48	0.02	0.42	0.35

Using Fmax, the maximum force reached during the wetting balance test, the maximum reading for the first dip was 0.18mN lower than the maximum reading for the second dip and this is visually evident from Figure 1. The results showed for Tb that 83% failed the limit of less than 0.6 seconds. The standard deviation was calculated to be 0.07 seconds for first dip and 0.02 seconds for second dip. Figure 2 is a good visual representation in that the stableness of the first dip compared with the seconds dip is much less.

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TFmax, time to reach maximum force, almost gave a linear line for the seconds dip results but for two readings. These two readings may have been as a result of poor solderability Cu wires. Again evidence of instability for the first dip is present and verified in Figure 3. There is a significant difference between the maximum value for the first and second dips, 2.84 seconds and 0.6 seconds respectively.

Using Ta, time to cross the x-axis on the wetting balance graph, Figure 4 shows the difference in results for the first and second dips. Overall the readings for the second dip are less than those for the second dip.

Appendix 1 shows a typical wetting balance graph for 14 readings – 7 readings first dip and 7 readings second dip.

The difference between first and second dip of the copper solder wire in terms of the responses, Fmax, Tb, TFmax and Ta, highlight the effect thermal conductivity of copper has and this adds to the fact the testing using a wetting balance machine for solderability of a copper wire surface will not give accurate readings because of this variation.

REFERENCES

[1] Woods, Bobby, A Capability Study of a Wetting Balance Machine using 0.9mm Diameter Copper Wires, FAIM2010
[2] Lea, C., A Scientific Guide to Surface Mount Technology, 1998
[3] MUST II Wetting Balance Machine User Manual.
[4] Joint Industry Standard – Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires, J-STD- 002C, December 2007.

Appendix 1 – Results of 7 Copper Wire Wetting Balance test – First and Second Dip

Test Details

Component	: Cu Wire 0.9mm (20mm length)		
Test parameter filename	: Bath Parameters.vts	Test parameter line	: 7

Test Limits and Conditions

F1	= 0.57 mN @ 2.00 s	F2	= 0.45 mN @ 5.00 s
Ta	= 1.00 s	Buoyancy	= -0.20 mN
Tb	= 0.60 s	Time 2/3 Fmax	= 1.00 s
Immersion Speed	= 20.0 mm/s	Immersion Depth	= 4.00 mm
Test Time	= 5 s	Pre-heat Time	= 0 s
Test Temperature	= 235.0 °C	Flux	= Pure Rosin

Description	Results Filename	Ta (s)	Tb (s)	T2/3 (s)	F1 (mN)	F2 (mN)	A.U.C. (mN/s)	Fmax (mN)	TFmax (s)	Pass/Fail
Cu Wire 0.9mm	(W090312 L01)	0.540	0.606	1.059	1.109	1.063	4.303	0.906	1.989	Fail
Cu Wire 0.9mm	(W090313 L01)	0.360	0.390	0.495	1.148	1.127	5.178	1.023	0.663	Pass
Cu Wire 0.9mm	(W090314 L01)	0.582	0.642	1.005	1.148	1.102	4.464	0.945	1.896	Fail
Cu Wire 0.9mm	(W090315 L01)	0.357	0.393	0.501	1.066	1.052	4.890	1.002	0.672	Pass
Cu Wire 0.9mm	(W090316 L01)	0.606	0.675	1.020	1.116	1.074	4.303	0.924	2.061	Fail
Cu Wire 0.9mm	(W090317 L01)	0.360	0.390	0.498	1.151	1.105	5.171	1.044	0.669	Pass
Cu Wire 0.9mm	(W090318 L01)	0.579	0.663	1.056	1.091	1.059	4.254	0.892	1.755	Fail
Cu Wire 0.9mm	(W090319 L01)	0.351	0.384	0.492	1.123	1.137	5.142	1.009	0.711	Pass
Cu Wire 0.9mm	(W090320 L01)	0.588	0.687	1.215	1.063	1.010	3.949	0.871	2.058	Fail
Cu Wire 0.9mm	(W090321 L01)	0.372	0.426	0.534	1.116	1.074	5.005	1.016	0.711	Pass
Cu Wire 0.9mm	(W090322 L01)	0.522	0.579	1.059	1.148	1.105	4.488	0.949	1.914	Fail
Cu Wire 0.9mm	(W090323 L01)	0.357	0.390	0.495	1.091	1.081	4.962	1.002	0.690	Pass
Cu Wire 0.9mm	(W090324 L01)	0.579	0.657	1.086	1.088	1.063	4.248	0.899	1.683	Fail
Cu Wire 0.9mm	(W090325 L01)	0.351	0.384	0.486	1.123	1.134	5.152	1.027	0.660	Pass
	Standard Dev	0.112	0.133	0.300	0.030	0.036	0.432	0.059	0.644	
	Mean	0.465	0.519	0.786	1.113	1.085	4.679	0.965	1.295	
	Max	0.606	0.687	1.215	1.151	1.137	5.178	1.044	2.061	
	Min	0.351	0.384	0.486	1.063	1.010	3.949	0.871	0.660	

Number of Tests : 014 **Passing rate :** 50.0 %