

**Solderability
Measurements of PCB
Pad Finishes
and Geometries**

**Deborah Lea, Fredrikus Jonck
and Christopher Hunt**

February 2001

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Head, The Materials Centre

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ABSTRACT:

As part of a DTI-sponsored programme to investigate lead-free soldering technologies, a study has been undertaken into the solderability of combinations of three lead-free solders (SnAgCu, SnCu, SnAg), three fluxes, and five lead-free printed circuit board (PCB) pad finishes (immersion Sn, immersion Ag, HASL SnPb, OSP and NiAu). The wetting characteristics of the various combinations have been measured using a wetting balance.

It is evident that to obtain acceptable wetting careful choice must be made of both the pad finish and flux. In general, boards with an OSP finish gave the best wetting results at all superheats and for all the lead-free solders studied, whilst the immersion tin finish gave the poorest wetting characteristics. The results also provide valuable information for PCB designers allowing them to predict the wetting forces as a function of pad size. The data indicate there is a simple relationship between pad area and wetting force, irrespective of the solder type. Moreover there is a linear relationship between pad width and wetting force or wetting time. In both cases only immersion Ag pads and an activated flux were studied. The behaviour is similar to that of conventional SnPb if allowance is made for the superheat.

A simple paste “dot” coalescence test has been shown to be valuable in ranking various process combinations. Its simplicity and inexpensive nature makes it an attractive option for in-house process evaluation.

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1. INTRODUCTION

Lead-free soldering is becoming an increasingly important issue due to rising environmental concerns and current legislation calling for a ban on the use of lead in electronic assemblies. A NPL/ITRI study^(1,2) has shown that lead-free soldering is technologically possible, but key implementation issues need to be addressed. The ease with which good solder joints can be made depends critically on the pad finish and on its wetting by the solder. The pad finish / solder combination is therefore a very important parameter for producing high quality electronic circuit assemblies. Hence this work aimed to characterise the solderability of lead-free solder alloys for different PCB pad finishes using the wetting balance test method. Pad size, as a function of both pad width and area was investigated for a lead-free alloy and a conventional tin-lead alloy.

The wetting balance test is the most useful tool for investigating the soldering properties of a combination of solders, surfaces and fluxes. Since its development, it has been used not only for assessing the solderability of PCB pads, but also the effect of solder alloy and flux. A typical wetting curve is shown in Figure 1. A very common solderability index is the wetting time T , the time passed until the force has reached two thirds of its maximum, measured from the buoyancy line. However, no specification is placed upon what that maximum force should be. Measuring the solderability for a range of pad sizes allows us to assess what forces can be expected with respect to pad dimension.

The use of T as an index implies a universal form to the wetting curve. In this project this index of wetting time is evaluated and used to assess the wetting property of different solder alloys with different PCB pad finishes and fluxes.

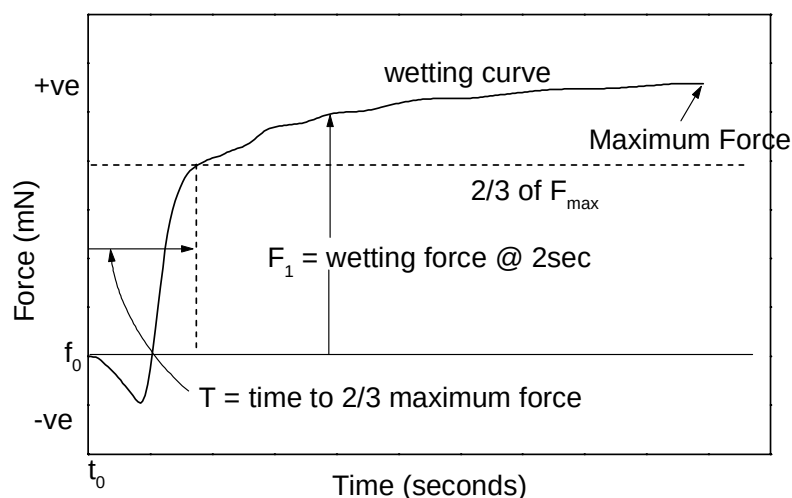


Figure 1 Schematic wetting balance curve with the wetting time defined.

An alternative method of assessing PCB solderability is to use solder paste with a typical reflow profile. In this test solder paste dots are printed with increasing separation onto long

pads and then reflowed. The reflowed sample is then inspected and by counting the number of the dots that have not coalesced a qualitative measure of solderability is achieved. The specific design used in this work is described later and shown in Figure 4. The advantage of this approach is that no special equipment is required other than standard assembly equipment. An advantage of the approach is that the method directly evaluates the PCB, solder paste and reflow conditions being used, and produces relevant information on the specific combination and hence any compatibility issues. A draw back is that the matching strips must be on the board for the test, and that the data is only qualitative.

2. EXPERIMENT

2.1 Alloys and fluxes

Five types of PCB pad finish: (immersion Ag, immersion Sn, OSP, SnPb HASL and NiAu) were evaluated using three lead-free solder alloys, SnAg, SnCu, SnAgCu (SAC), and conventional SnPb. The pads were tested with three fluxes: 0.5% activated rosin, pure rosin, and a low solid no-clean flux. Details of alloys and fluxes are given in Table 1. The first two fluxes are a standard formulation in compliance with IEC 68-2-20. An identical nomenclature of naming fluxes is kept with Ref3. Flux A and D are the rosin based fluxes and B is the no-clean flux. To evaluate the PCB surface finishes six pads identified with pad code D33 from board TB26 (bottom side), see Figures 2 and 3 were tested for each condition. The D33 pads are those used for 1812 capacitors, and details of all pads are given in Table 2.

2.2 PCB design

For pad size comparison, one set of test parameters were selected: Ag finish, 0.5% activated rosin flux, 40⁰C superheat, and tested with two alloys: SnPb and SnAgCu, six pads for each size were tested. Superheat temperature is defined as the difference between the soldering temperature and the solder alloy melting point. The test results are presented as an average value from the test samples. Figures 2 and 3 show the design for the PCB, the coupon measures 30 x 30 mm, is double sided and is identified as TB26.

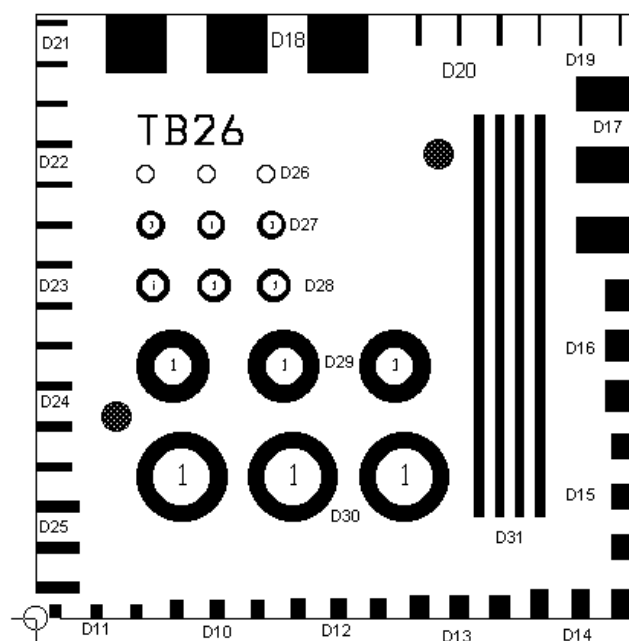


Figure 2: Test board TB26 'top'

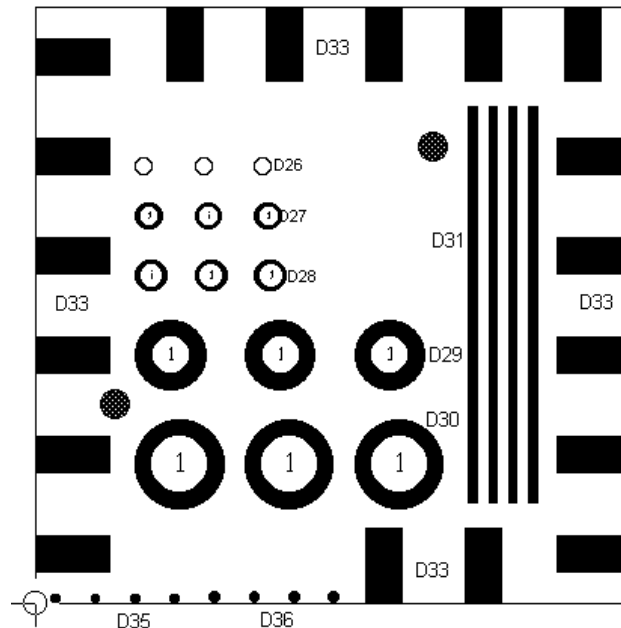


Figure 3: Test board TB 26 'bottom'

Tables 1 and 2 give the technical data for the PCB pad finishes, solder alloys, fluxes and pad sizes. The fluxes are the same as for a previous solderability study⁽³⁾.

Table 1: Details of Test Flux, Alloys and Temperatures

Flux	Description	
A	Pure rosin, 0.5% halide activated flux	
B	Low solids, no-clean, non-halide activated flux	
D	Pure rosin, non-activated flux	
Alloy	Composition %	Melting point °C
SnAgCu	95.5/3.8/0.7	217
SnAg	96/4	221
SnCu	Pellet: 99.5/0.5	227
SnPb	60/40	183
Superheat °C	20 / 25*, 30, 40	

* SnAg sometimes does not reach a liquidus state with some fluxes at 20° C superheat on the heating stub in the wetting balance. This is due to the hard oxide formed on the globule. In these cases 25° C superheat was used instead.

Table 2: Details of pad sizes and corresponding footprint

Pad code	Footprint	Width mm	Length mm	Area mm ²
D10	0402B	0.6985	0.8992	0.6281
D11	0402	0.5994	0.6985	0.4187
D12	0603B	0.8001	1.0008	0.8007
D13	0603	1.0008	1.0998	1.1007
D14	0805B	0.8992	1.3995	1.2584
D15	0805	1.3005	1.4986	1.9489
D16	1206	1.6002	1.7983	2.8776
D17	2512	1.7983	3.2004	5.7553
D18	SQ3X3	2.9997	2.9997	8.9982
D19	S/QFP1	0.1702	1.6002	0.2724
D20	S/QFP2	0.2489	1.6002	0.3983
D21	S/QFP3	0.2997	1.6002	0.4796
D22	S/QFP4	0.3505	1.7983	0.6303
D23	S/QFP5	0.3988	1.7983	0.7172
D24	S/QFP6	0.5004	1.7983	0.8999
D25	SOIC	0.5994	2.1996	1.3184
D26	Hole 1	0.8992	0.7490**	0.1944
D27	Hole 2	1.3995	0.8990**	0.9031
D28	Hole 3	1.6485	1.1000**	1.1834
D29	Hole 4	3.5992	1.7990**	7.6285
D30	Hole 5	4.4983	2.8000**	9.3698
D31	Dot test pad			
D33	1812 CAP	1.8999	3.7998	7.2192
D35	Round 1	0.5004	0.5004	0.1966
D36	Round 2	0.5994	0.5944	0.2773
D40	Fiducle			

** inner hole measurement

Pad sizes conform to: IPC SM-782 standard

2.3 Dot test stencil:

A mini stencil was used to stencil print solder onto the dot test pads (D31) on board TB26. The design of the stencil can be seen in Figure 4. The pitch is variable; the smallest value starts in the bottom left hand corner and is 0.70 mm. The pitch increases incrementally from left to right by 0.01 mm, 0.71, 0.72 and so on, until it reaches a value of 0.92 mm at the bottom right hand corner. The second row from the bottom starts with a pitch of 0.90 mm and increases incrementally by 0.02mm to reach a value of 1.24 mm on the far right. Row three from the bottom starts with a pitch of 1.10 mm and increases incrementally by 0.03 mm to reach 1.49 on the far right, and lastly the top row starts at 1.30 mm and increases incrementally by 0.04 mm until it reaches 1.74 mm on the far right hand side.

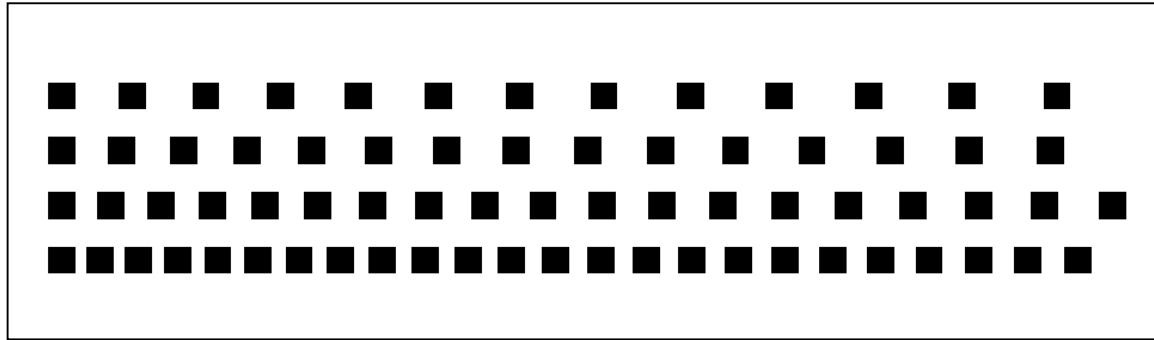


Figure 4 Dot Test Stencil

For pad size comparison, F1 the force at 2 seconds (mN) and T the wetting time to 2/3 maximum force (seconds) were measured. Tables 3 and 4 give the test results as functions of pad width and pad area respectively.

Table 3: Solderability Results for Pad Width

Code	Width mm	SnPb	SnPb	SnAgCu	SnAgCu
		F1 mN	T secs.	F1 mN	T secs.
D19	0.1702	0.15	0.13	0.12	0.11
D20	0.2489	0.22	0.13	0.2	0.14
D21	0.2997	0.23	0.11	0.31	0.13
D22	0.3505	0.2	0.12	0.31	0.12
D23	0.3988	0.41	0.14	0.28	0.13
D24	0.5004	0.44	0.15	0.52	0.16
D35	0.5004	0.13	0.10	0.10	0.10
D11	0.5994	0.17	0.11	0.17	0.11
D25	0.5994	0.43	0.18	0.61	0.15
D36	0.5994	0.08	0.10	0.18	0.12
D10	0.6985	0.31	0.13	0.27	0.13
D12	0.8001	0.44	0.15	0.47	0.13
D14	0.8992	0.76	0.2	0.78	0.15
D26	0.8992	0.58	0.21	0.55	0.17
D13	1.0008	0.61	0.14	0.55	0.16
D15	1.3005	1.12	0.16	1.29	0.18
D27	1.3995	1.15	0.19	0.47	0.17
D16	1.6002	1.28	0.2	1.57	0.18
D28	1.6485	1.42	0.2	1.04	0.21
D17	1.7983	1.66	0.22	1.72	0.27
D33	1.8999	1.71	0.28	2.1	0.23
D18	2.9997	2.78	0.32	2.8	0.3
D29	3.5992	3.17	0.52	1.91	0.22
D30	4.4983	3.94	1.32	4.27	1.09

Table 4: Solderability Results for Pad Area

		SnPb	SnPb	SnAgCu	SnAgCu
Code	Area mm ²	F1 mN	T secs.	F1 mN	T secs.
D26	0.1944	0.58	0.21	0.55	0.17
D35	0.1966	0.13	0.1	0.1	0.1
D19	0.2724	0.15	0.13	0.12	0.11
D36	0.2773	0.08	0.1	0.18	0.12
D20	0.3983	0.22	0.13	0.2	0.14
D11	0.4187	0.17	0.11	0.17	0.11
D21	0.4796	0.23	0.11	0.31	0.13
D10	0.6281	0.31	0.13	0.27	0.13
D22	0.6303	0.2	0.12	0.31	0.12
D23	0.7172	0.41	0.14	0.28	0.13
D12	0.8007	0.44	0.15	0.47	0.13
D24	0.8999	0.44	0.15	0.52	0.16
D27	0.9031	1.15	0.19	0.47	0.17
D13	1.1007	0.61	0.14	0.55	0.16
D28	1.1834	1.42	0.2	1.04	0.21
D14	1.2584	0.76	0.2	0.78	0.15
D25	1.3184	0.43	0.18	0.61	0.15
D15	1.9489	1.12	0.16	1.29	0.18
D16	2.8776	1.28	0.2	1.57	0.18
D17	5.7553	1.66	0.22	1.72	0.27
D33	7.2192	1.71	0.28	2.1	0.23
D29	7.6285	3.17	0.52	1.91	0.22
D18	8.9982	2.78	0.32	2.8	0.3
D30	9.3698	3.94	1.32	4.27	1.09

3. RESULTS AND DISCUSSION

3.1 PCB SURFACE FINISH WETTING

3.1.1 SnAgCu Solder Alloy

The wetting times for all the pad finishes are presented in Figures 5-7. The values are plotted against superheat for fluxes A, B and D, and all tests were carried out in air with SnAgCu solder alloy. For flux A, all finishes apart from immersion tin had good wettability at all superheat temperatures. Flux D gave a similar response to flux A, however superheat temperatures of approximately 10°C higher were required to obtain similar wetting to flux A. As with flux A, immersion tin finish gave the poorest wetting results for flux D. Wettability was significantly degraded when using flux B, even with a superheat of 40°C. The results for all fluxes indicated that some ‘ranking’ of the pad finish was apparent, with Ag and OSP

giving the best wetting times, and immersion tin giving the poorest wetting times for this solder alloy.

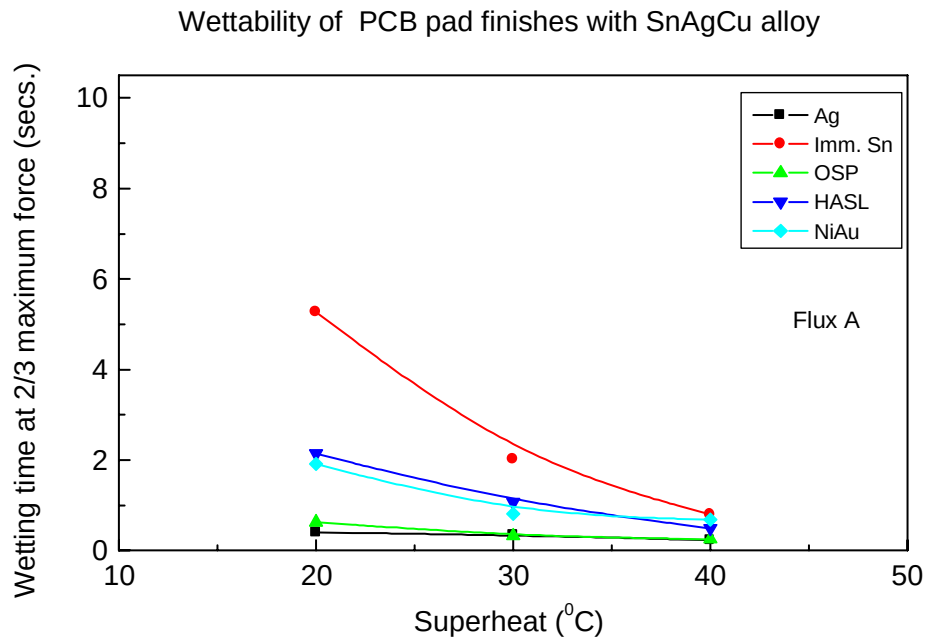


Figure 5: SnAgCu alloy and flux A

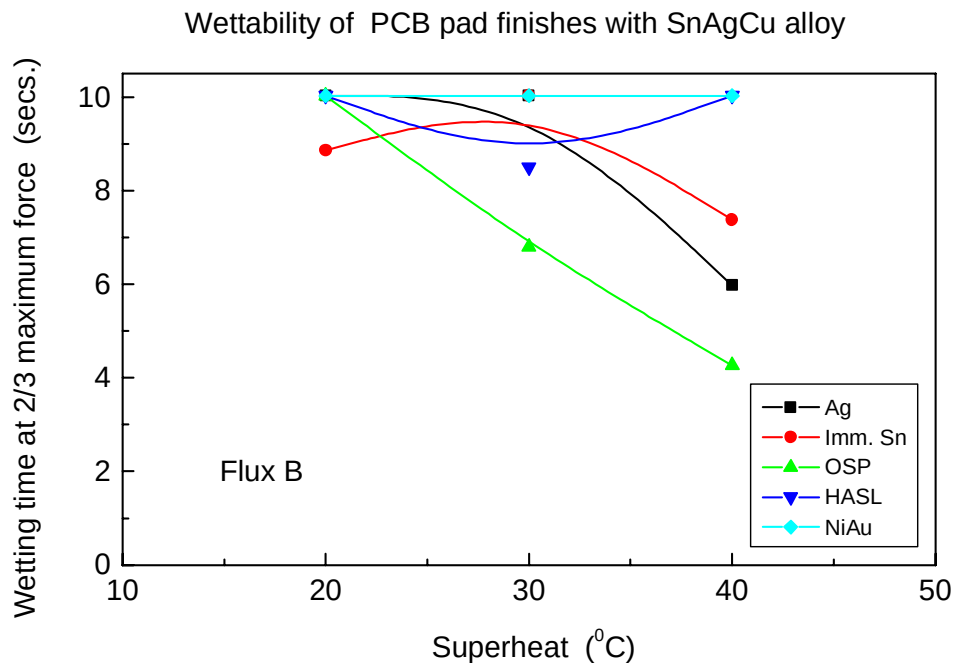


Figure 6: SnAgCu alloy and flux B

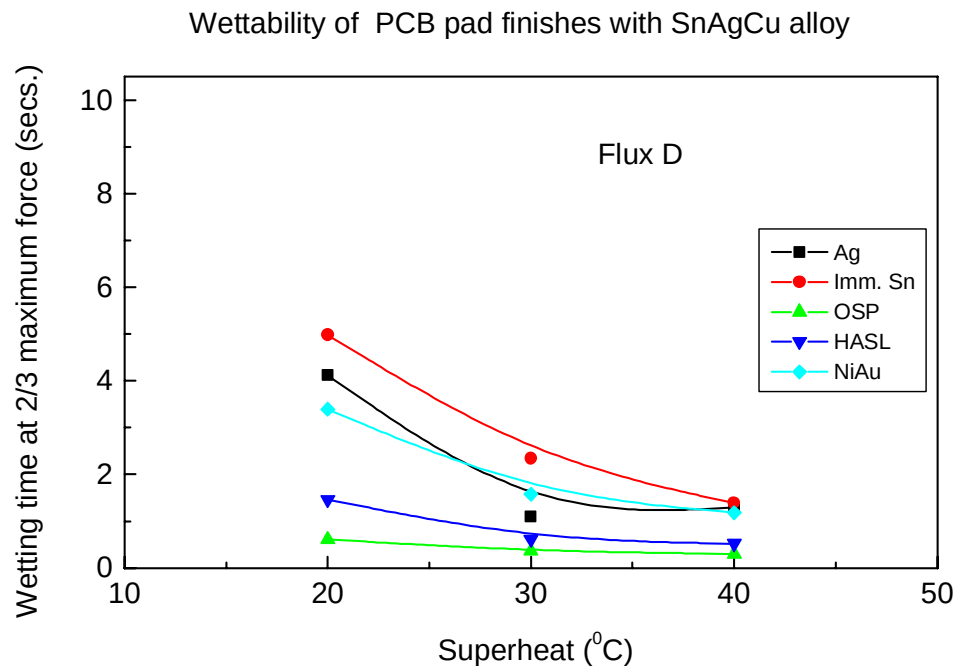


Figure 7: SnAgCu alloy and flux D

3.1.2 SnCu Solder Alloy

The wetting times for all the PCB pad finishes are shown in Figures 8-10. The values are plotted against superheat for SnCu alloy and fluxes A, B and D, and all tests were carried out in air. For flux A, all finishes apart from immersion tin had good wettability for a superheat of 30°C or higher. Flux D gave good wetting for all pad finishes for a superheat of 40°C. As with flux A, immersion tin finish gives the poorest wetting results for flux D. Wettability was significantly reduced with flux B, even at the highest superheat of 40°C, none of the pad finishes having acceptable wetting times with SnCu solder. The results indicated that the same 'ranking', as observed with the SnAgCu solder, of the pad finish was apparent. HASL and OSP giving the best wetting times, and immersion tin having the poorest wetting.

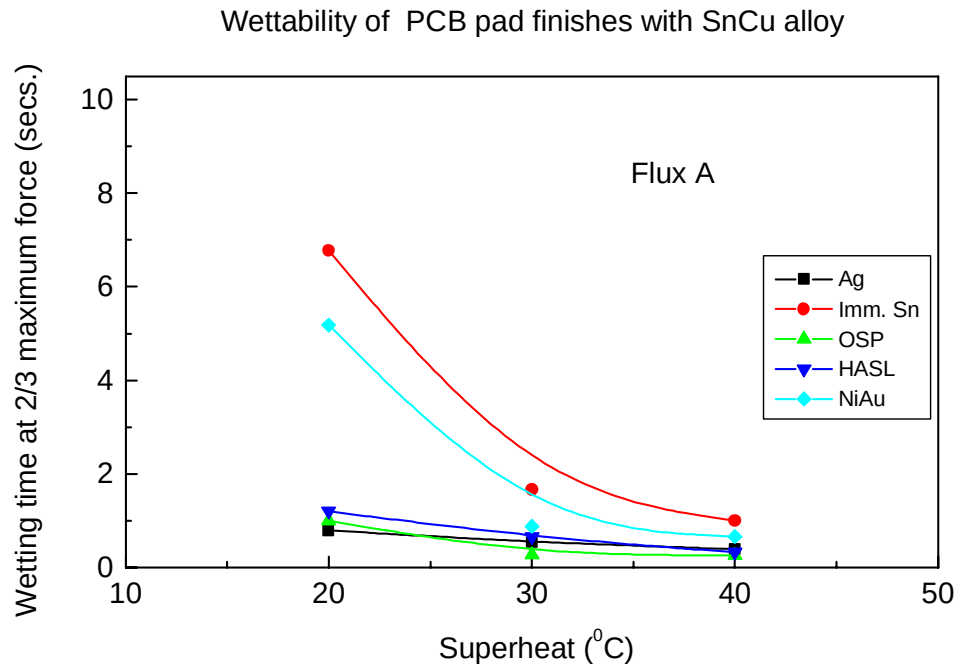


Figure 8: SnCu alloy and flux A

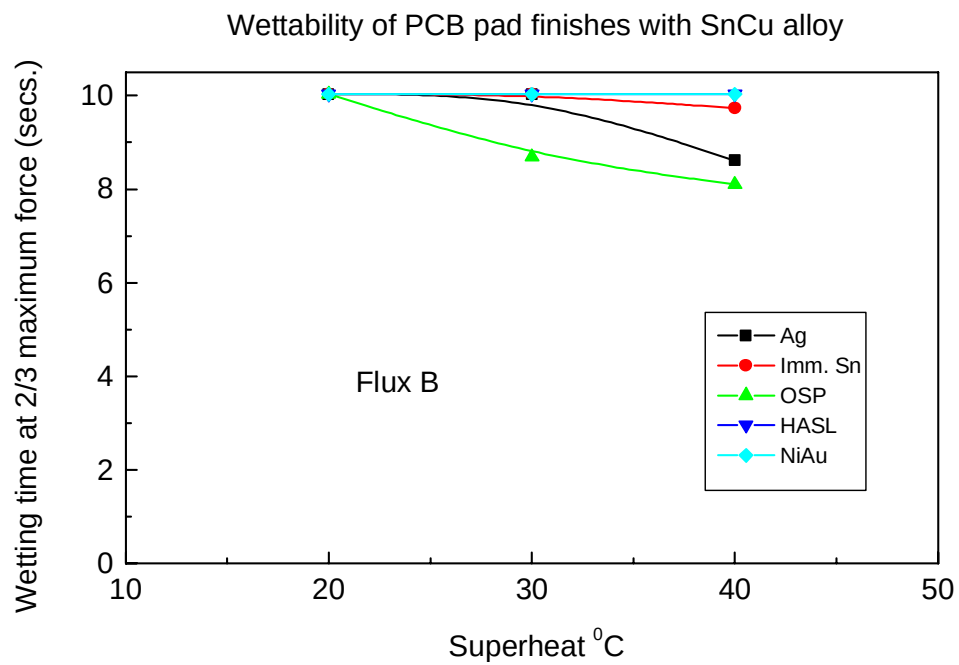


Figure 9: SnCu alloy and flux B

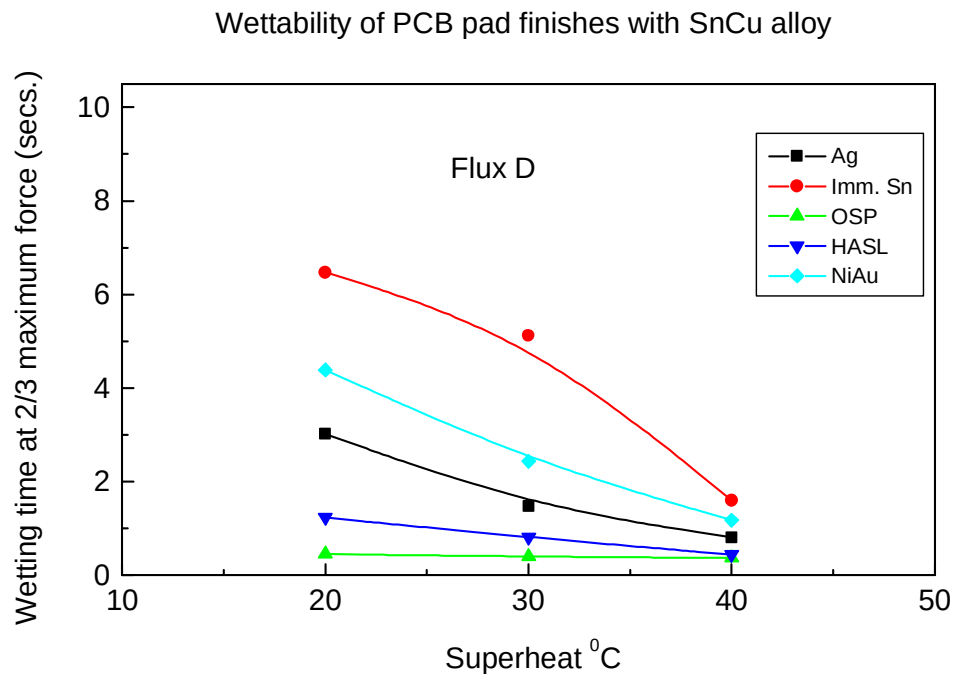
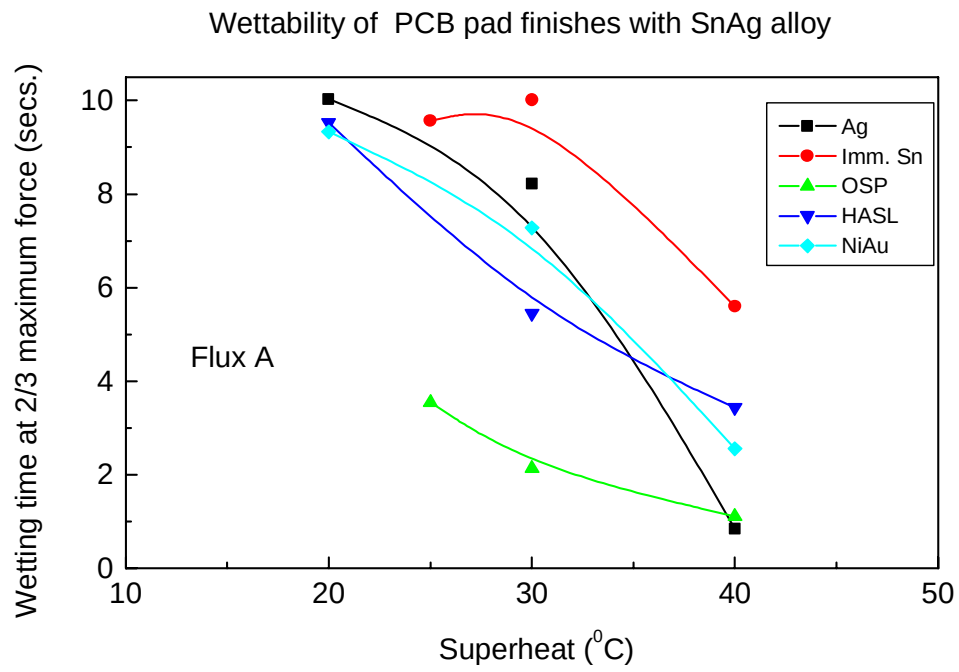
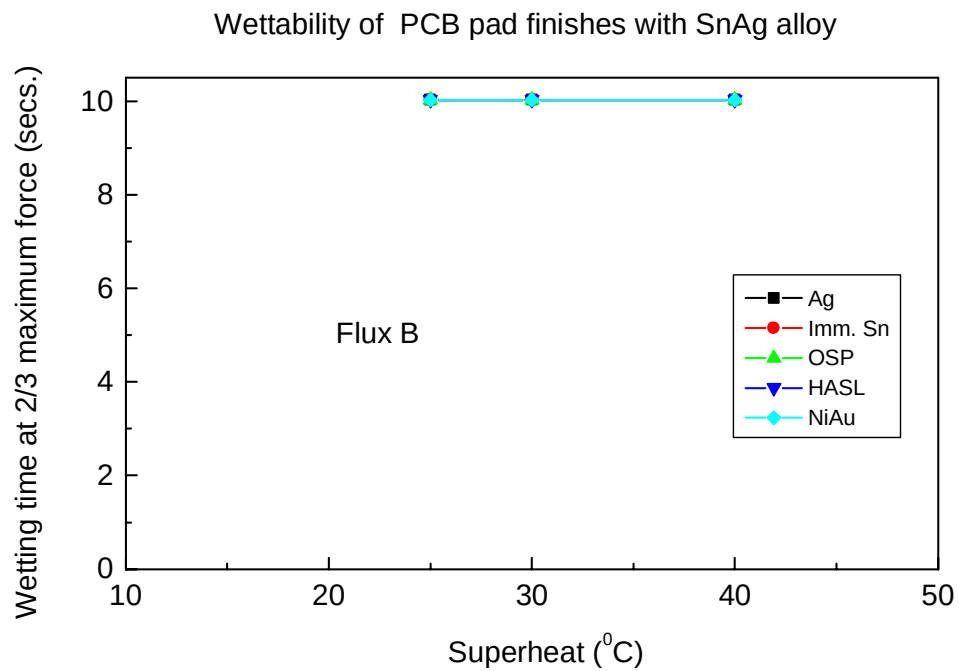


Figure 10: SnCu alloy and flux D

3.1.3 SnAg solder alloy

The wetting times with SnAg are shown in Figures 11-13, for fluxes A, B and D. Fluxes A and D gave poor wetting for all finishes at the lowest superheat. Wetting became acceptable for the OSP finished pads but only at the highest superheat for both fluxes. The Ag finish also gave acceptable wetting with flux A at the highest superheat. As for the other lead-free solder alloys, flux B gave very poor wetting results. No wetting was observed for any of the pad finishes, at all superheat temperatures, when using flux B.

**Figure 11: SnAg alloy and flux A****Figure 12: SnAg alloy and flux B**

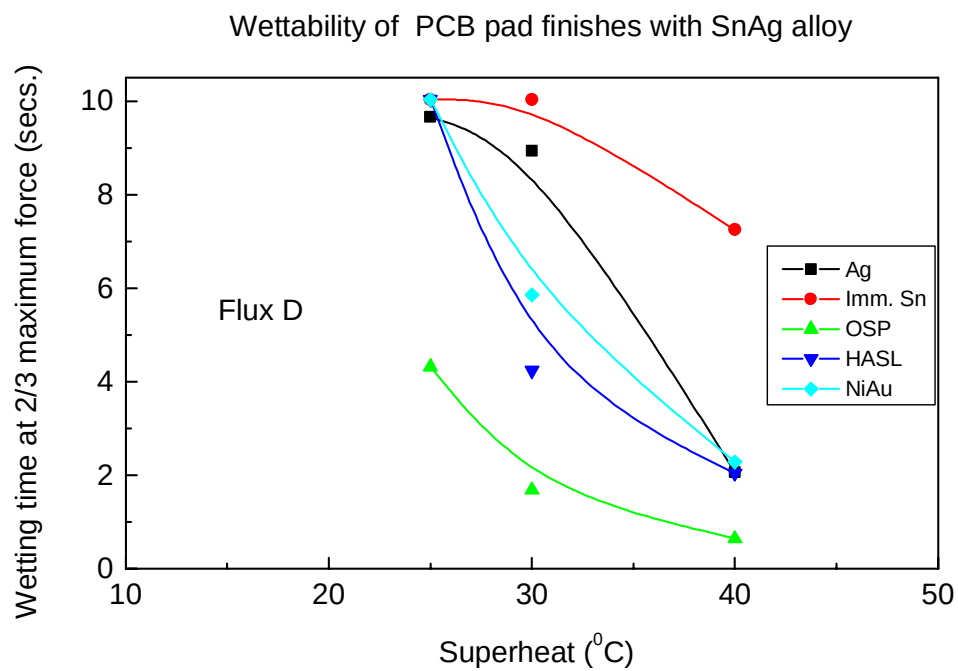


Figure 13: SnAg alloy and flux D

3.1.4 SnPb Solder Alloy

The wetting times for the SnPb alloys are shown in Figures 14-16. Flux A gave good wetting for all finishes apart from NiAu. HASL and immersion tin required superheats greater than 30°C for acceptable solderability. The Ag finish gave the best wetting with all fluxes. Wettability was again very poor with flux B, only the Ag pad finishes had acceptable wetting times with SnPb solder alloy at the highest superheat temperature. NiAu had unacceptable wetting with SnPb alloy with all three fluxes and all superheats.

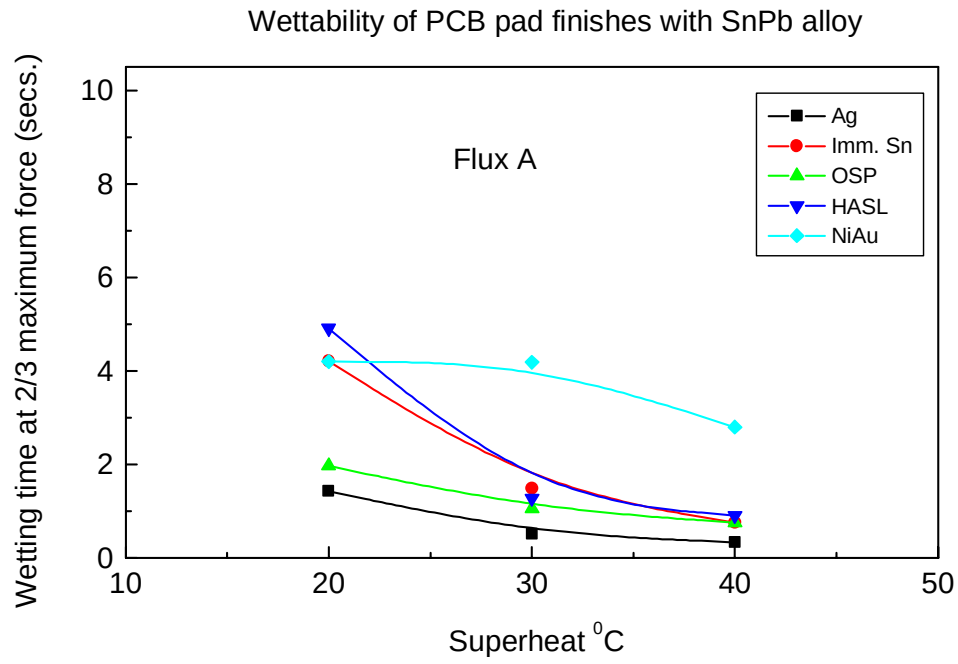


Figure 14: SnPb alloy and flux A

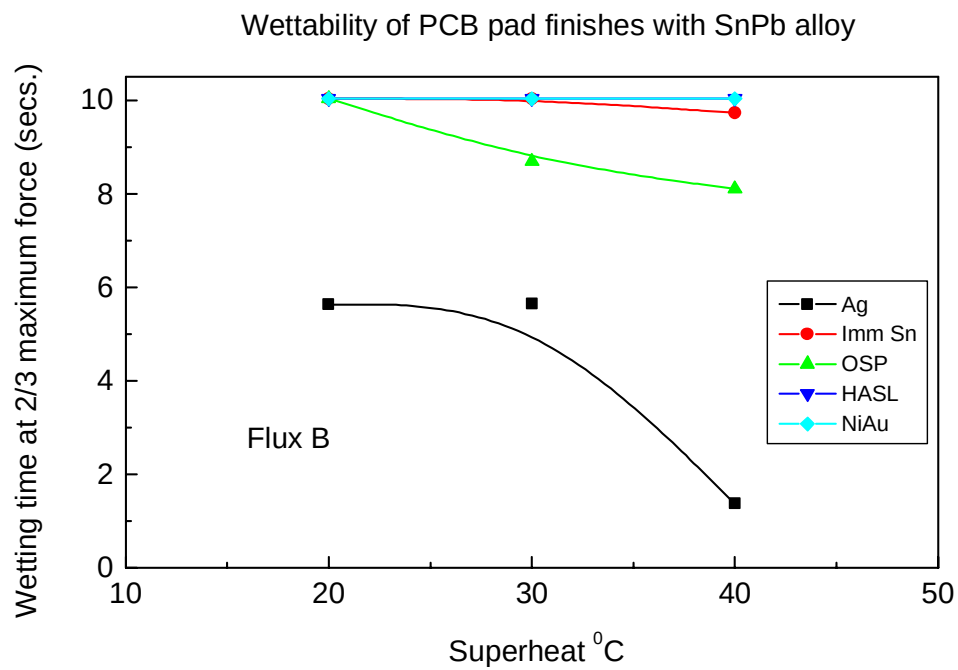


Figure 15: SnPb alloy and flux B

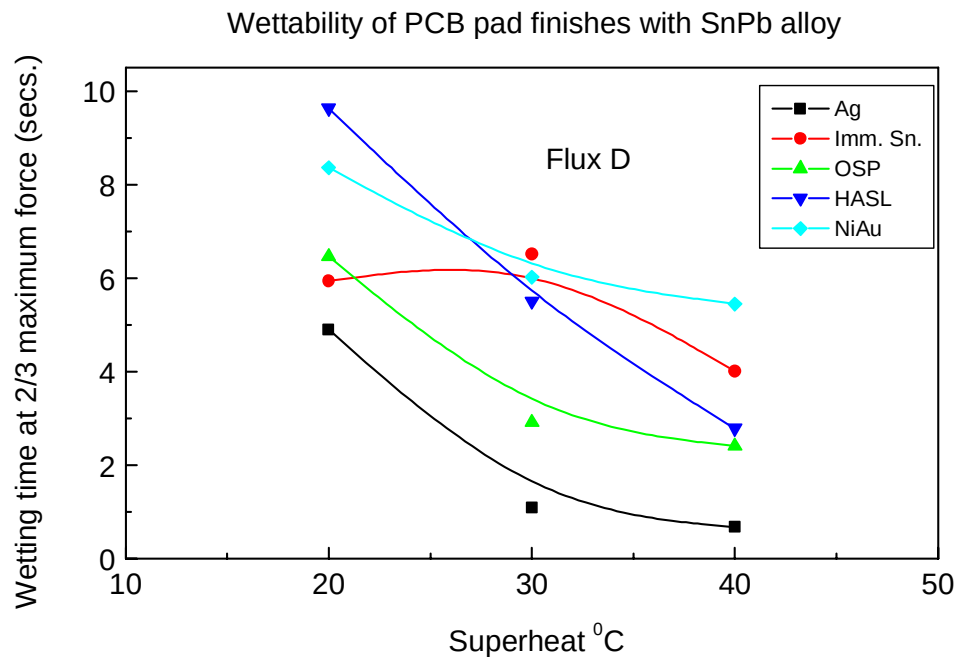


Figure 16: SnPb alloy and flux D

3.2 PAD FINISH INTERCOMPARISON

The results show that for all the four solder alloys tested, superheat is an important factor to be considered for the majority of the PCB pad finishes. Flux choice also plays an important role. Of the three fluxes tested, flux B significantly diminished the solderability of all the board finishes to the extent that they were unsolderable, regardless of choice of alloy.

3.3 PAD SIZE

The effect of pad size on wetting was measured for the Ag finished PCBs with both a lead-free and conventional tin-lead solder alloy, using flux A (0.5% activated pure rosin), at 40⁰ C superheat. The results shown in Figures 17 and 18 indicated that the wetting with the lead-free alloy on Ag finished boards using an activated flux, broadly follows that of SnPb alloy, if allowance is made for the melting point. Resulting wetting forces, and wetting times were dependent on pad size, but similar for both tin-lead and lead-free alloys. The results in Figures 17 and 18 do not include the through hole pads as their geometry differed significantly from that of surface mount pads. The wetting force results follow a square root function with pad area, as shown by the square root function drawn in Figure 18.

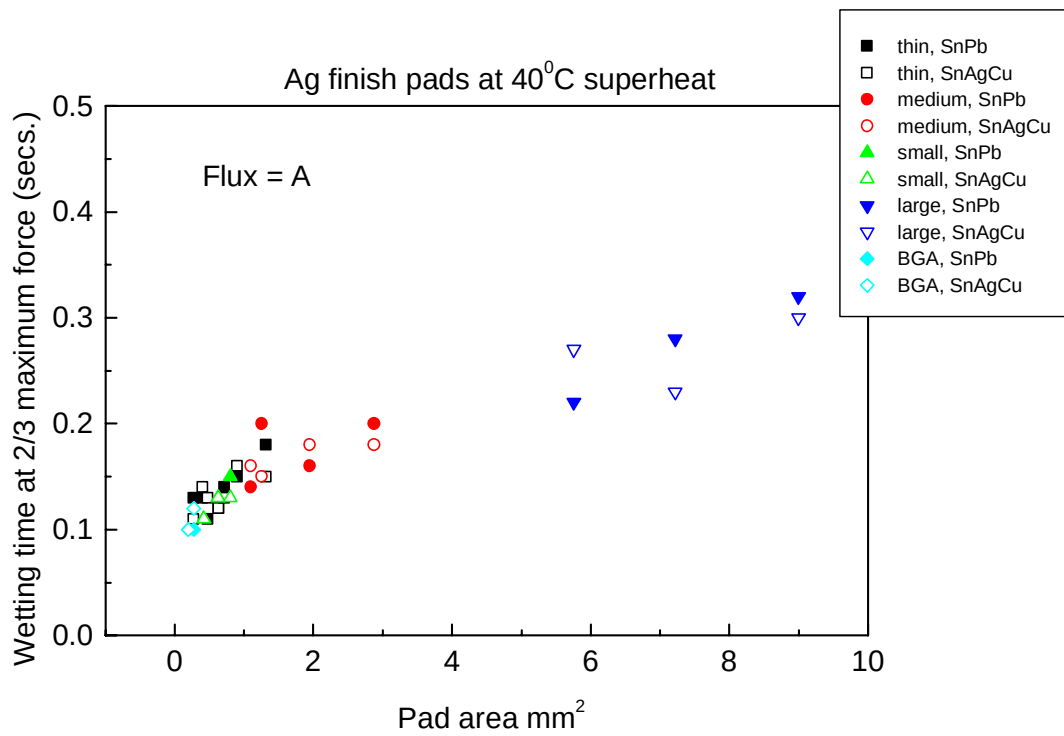


Figure 17 Pad area and wetting time (secs.)

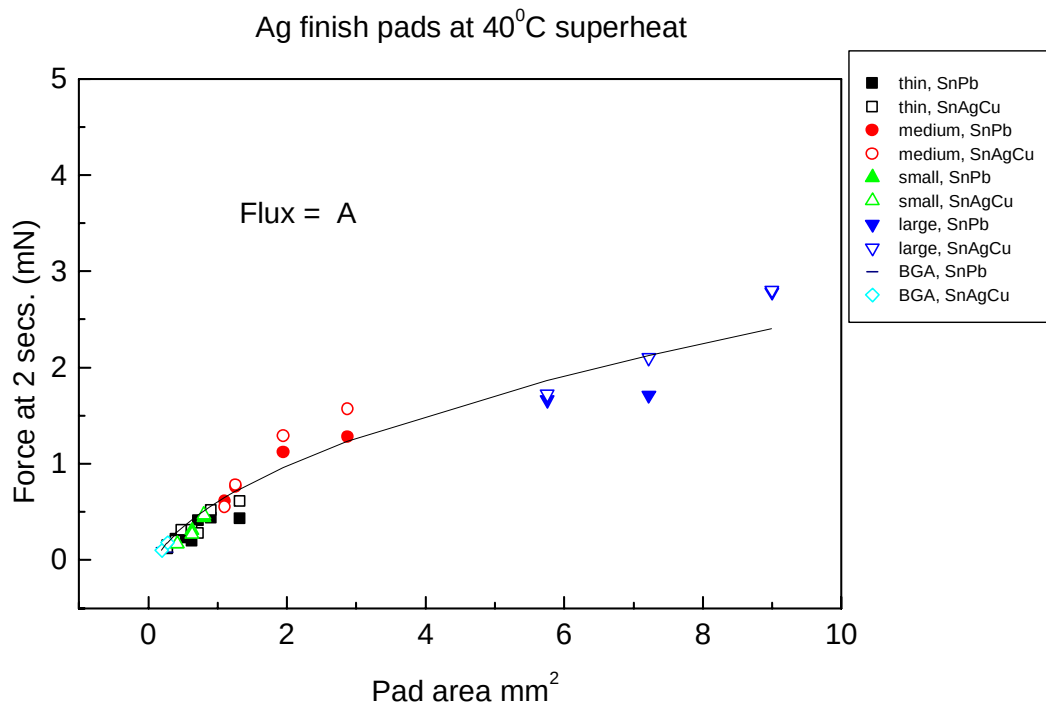


Figure 18 Pad area and wetting force (mN)

Figures 19-20 present the results for wetting force and wetting time as a function of pad width. The results show that there is a linear relationship with pad width, for both wetting time and wetting force.

Clustering is apparent for pads with a similar geometry, and is present for both wetting time and wetting force for these pad shapes. It is clear from the results that both force and wetting time correlate well with pad width and area for surface mount pads.

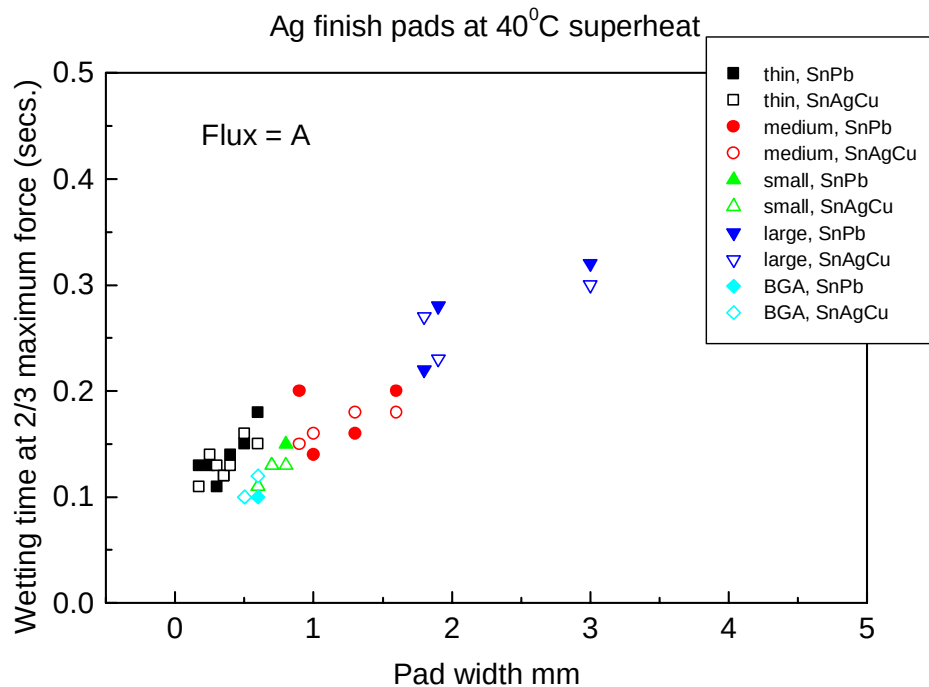


Figure 19: Pad width and wetting time (secs.)

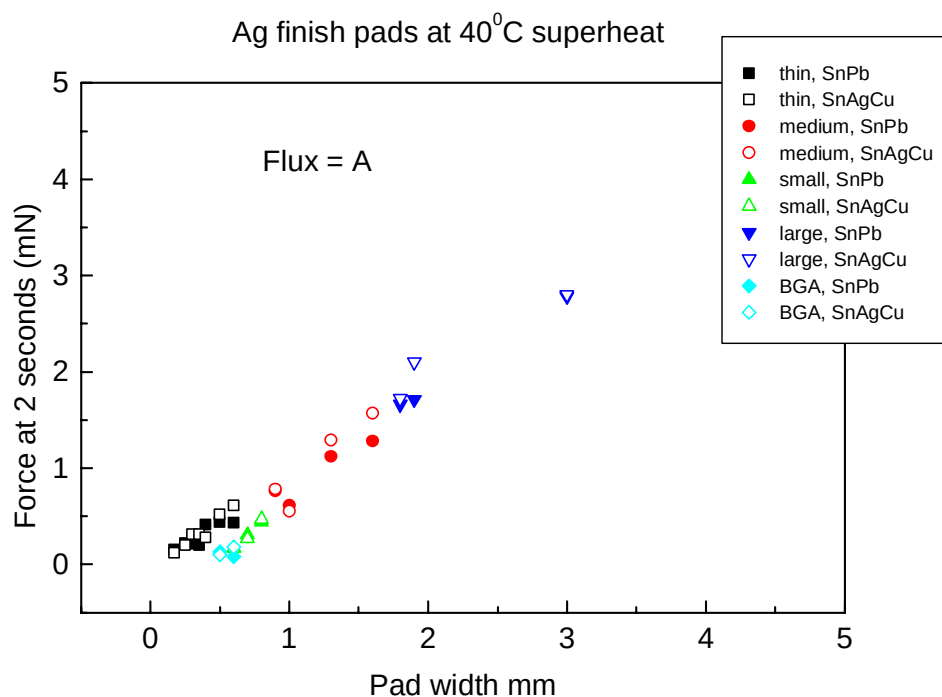


Figure 20: Pad width and wetting force (mN)

3.4 'DOT' TESTS

Five boards for each PCB pad finish were stencil printed and reflowed at three sites. The pads identified as D31 on coupon TB26 were manually stencilled printed using a mini stencil and reflowed. The first set was printed and reflowed at site no.1 with a no-clean SnAgCu solder paste. The second set at site '2' was with a different no-clean SnAgCu solder paste. At site 3 a SnPbAg solder paste was used. The number of dots that did not coalesce was counted for each board and a mean value for each finish recorded. This was repeated for each assembly site. Figure 21 shows a test coupon after reflow. The results are shown in Table 5 and presented graphically in Figures 22-24.

Table 5
Mean number of uncoalesced dots for PCB pad finish and assembly site

Site	Ag	Imm. Sn	OSP	SnPb HASL	NiAu
'1'	21.6	38.2	66.6	10.2	47.6
'2'	7.7	4.2	31.5	6.3	10
'3'	38	0	2	0	8

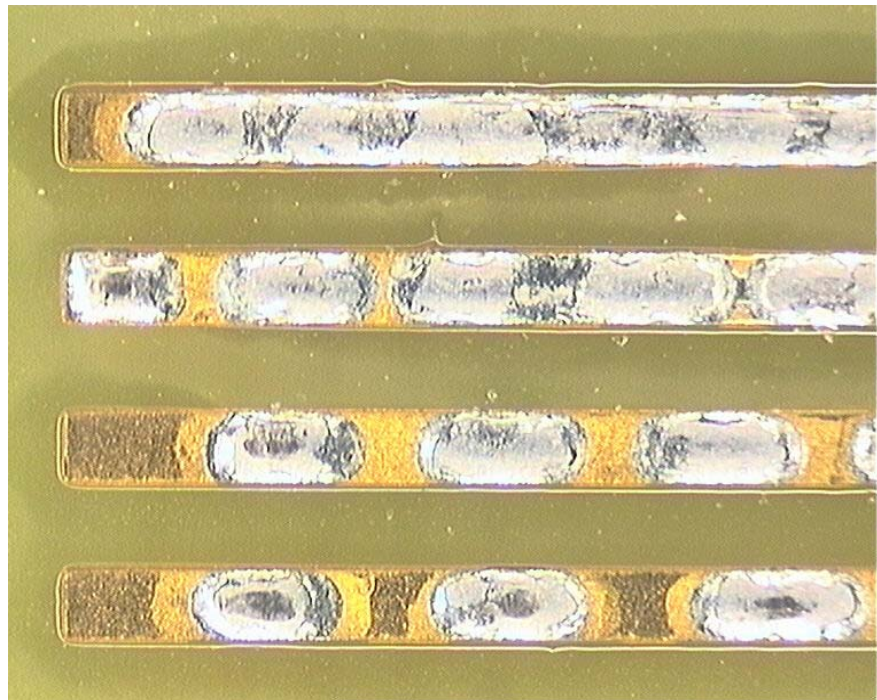
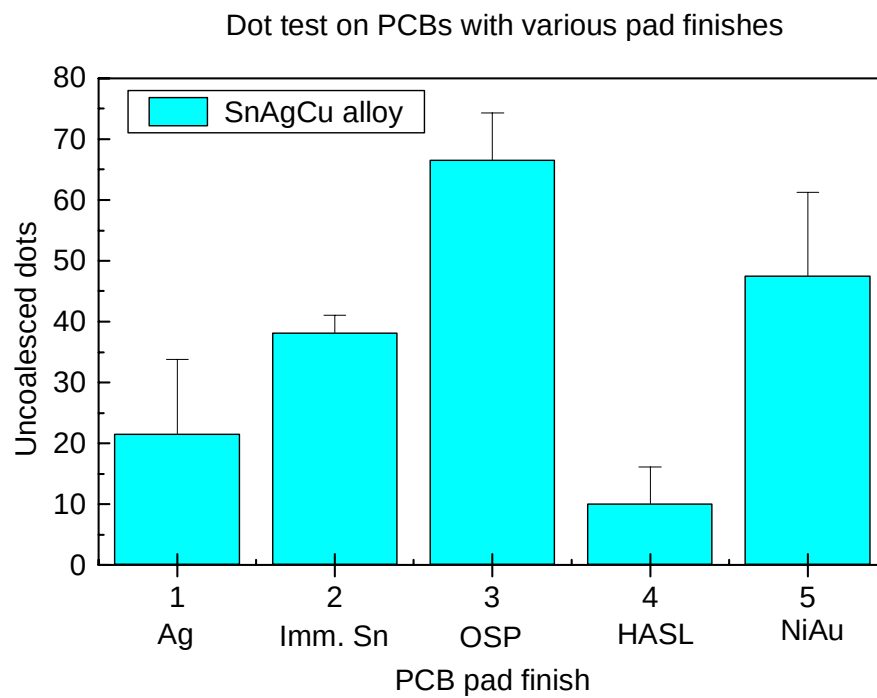
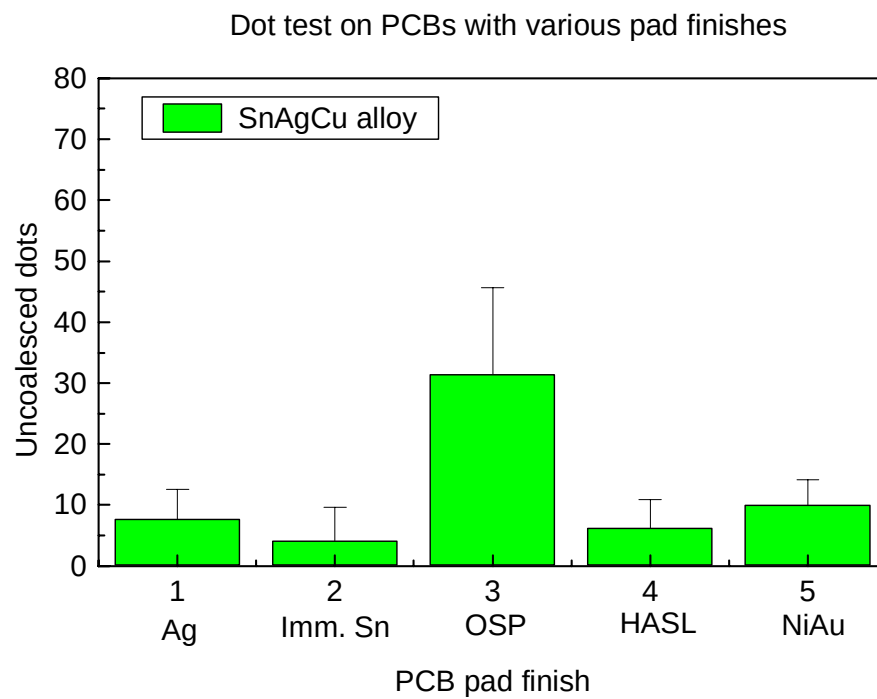


Figure 21: Dot test coupon after reflow

**Figure 22: Dot test site 1****Figure 23: Dot test site 2**

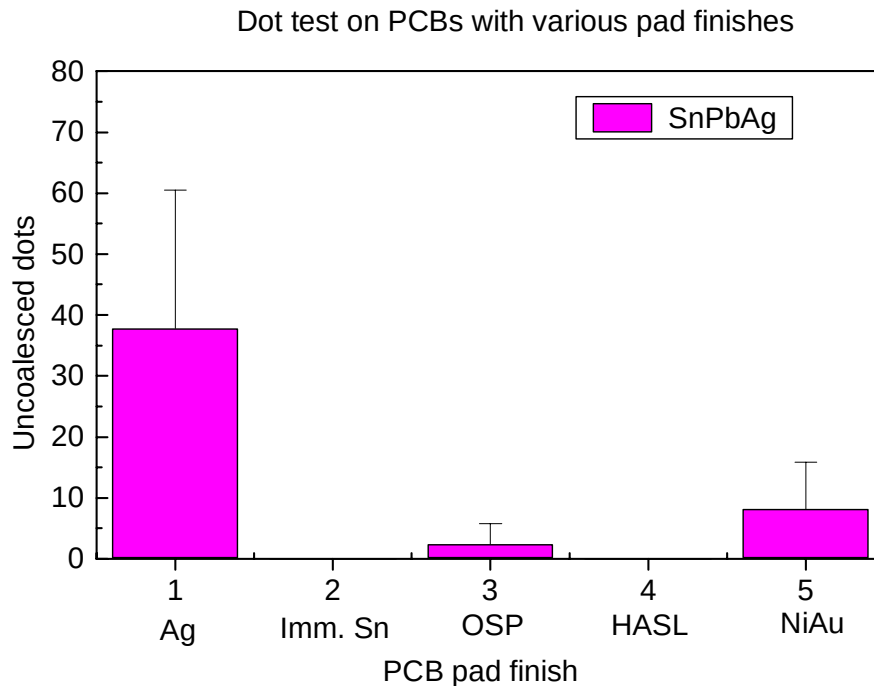


Figure 24: Dot test site 3

The results of this test suggests that board assemblers can assess board finishes using their own assembly process. Coupons stencilled printed using the assemblers' own pastes and reflowed using their own process will be able to rank board finishes using the dot test. Clearly site No.3 achieved excellent solderability with all finishes, except the Ag finish. Site No.1 struggled with all finishes, and reflects some issues with the small reflow system used. The response with the different finishes did vary between the different sites, reflecting the sensitivity to matching flux chemistry and surface finish. It is interesting that the HASL finish always performed well. In moving to alternative finishes care will be needed in achieving good yields, to match flux and reflow profile, particularly with the lead-free alloys.

4. CONCLUSIONS

As part of a DTI programme to characterise solderability using lead-free alloys the wetting of various PCB finishes with three alloys (SnAgCu, SnAg, SnCu) has been measured. The PCB test vehicle comprised an array of pad designs, permitting the wetting properties to be correlated with pad design. A number of specific conclusions can be drawn:

- The solder alloy and flux are important in determining the wetting characteristics of PCB pad finishes. In general, the SAC alloy gave the best results, but the solderability was more affected by choice of flux.
- The solderability of the SAC alloy was best when using flux 'A'. All the finish/solder alloy combinations gave poor wetting results when used with flux 'B' for all superheats.
- Overall, boards with an OSP finish gave the best wetting results (and immersion tin the poorest) at all superheats with lead-free solder alloys.

- With pad design a square root relationship was established between pad area and wetting force. Also, both wetting force and wetting time correlate well with pad width, following a linear behaviour for all alloys. Clustering can be seen for pads with a similar geometry for both wetting time and wetting force.
- The response of wetting time and wetting force to vary pad size follow a very similar pattern when using conventional SnPb and lead-free alloys for Flux A.
- The dot test data demonstrate that PCB assemblers can use the test to rank board finishes for their own process and other process materials. This is a relatively simple test to perform and does not require any sophisticated equipment. The design is easy to incorporate onto existing PCB layouts and is easy to run.

5. REFERENCES

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