REPORT
Project Nr. B033353
Lead free manufacturing

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Also see:
http://www.tycoelectronics.com/leadfree

SUMMARY

Materials information only is insufficient to assess the compatibility of a part with leadfree soldering. The part geometry is a major factor of influence which varies independently of the materials. Some examples of this are given. As a result, the compatibility of a part with leadfree soldering should be assessed on a case-by-case basis by the responsible Product Engineer. Preliminary guidelines are given as well as sources of support.
More work is needed to develop these guidelines into design rules for leadfree connectors. As Pb is proven to be a major factor in the press-in assembly sequence, with press-fit products there is a potential concern of reduced reliability due to lower retention force or changed conditions during assembly with finishes other than the conventional tin-lead.

1. Introduction.

The ROHS[1] directive proposed by the European Commission imposes a ban on the following substances: lead, mercury, cadmium, hexavalent chromium and PBB and PDBE's (halogenated flame retardants.)

The RoHS implementation date is 1JUL2006 with a companion directive in WEEE that takes effect 1JAN2007. The ELV directive takes effect 1JUL2003.

The real driver is market pressure. Most global companies in Europe want to change to leadfree production within the next two years.

This report deals with the effects of a ban on lead on different categories of product as defined by their construction materials.

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[1] WEEE = Waste Electrical and Electronic Equipment, ROHS = Restriction of the use of certain Hazardous Substances in electrical and electronic equipment. Both directives are treated as one. The ELV directive governs automobile industry only. Copies of the EU directives are available at www.tycoelectronics.com/leadfree.

2. Product categories

Product categories were created, based on the material from which they are made and on the termination method. Products considered representative for each category were tested. The categories are shown in table 1, the determining factors are described below.

2.1. Plating layer

Lead will be banned, so tin-lead layers should be replaced by something else. This is the case for all products. At the present moment there is not one preferred solution. For this project a commercially available "whiskerfree" pure tin was chosen.

2.2. Plastic

The new leadfree solders, mostly SnAgCu-types, for wave soldering sometimes SnCu, have melting points of 217°C and 227°C respectively. The current eutectic SnPb solder has a melting point of 183°C. This results in higher temperatures during the solder process. Maximum temperatures of 260°C to 280°C or higher are mentioned, both for reflow and for wave soldering.

In certain cases the plastic of solder products is affected and will have to be changed. The criteria chosen here are the melting point and the heat deflection temperature (ISO: HDT @ 1.82MPa) of the plastic. A change of plastic is needed when either of these is lower than the maximum temperature during the soldering process. For some products this is not immediately evident due to the variation in temperature over the product or between the processes as used by different customers.

2.3. Termination method

Surface mount parts are fully exposed to the high temperatures in the reflow oven. All solder joints on the pcb have to reach the solder temperature, including those which are most difficult to heat up. Consequently, other components on the pcb will reach higher temperatures, especially small components which heat up fast (e.g. a thin SIM connector) as well as the top side of components which stand high above the pcb surface, (most connectors as compared to other components). How much higher these temperatures will be depends on the type of reflow oven, the temperature profile and in particular the design of the pcb assembly. This cannot be predicted.

In wave soldering the plastic of the housing is heated up locally by heat flowing upwards through the solder leg. This can influence the holding force of a contact which is pressed in the housing.

Also in hand soldering, the housing is heated up locally by heat conduction through the solder leg. With leadfree solder, higher temperatures of the soldering iron may have to be used.

For press-fit products there are obviously no problems with soldering heat. The concerns here are variations in insertion and retention force due to different friction and deformation conditions and the possible formation of whiskers on pure tin platings under the influence of the stresses in the press-fit connection. Similar concerns may arise for other non-solder parts, like IDC or crimp parts. These have not yet been considered.

Cat.	termination method		plating layer	plastic	action	products tested:
A	solder		No Pb	HDT OK	none	SIM card connector
B	solder	reflow	SnPb	HDT/Tmelt OK	change plating layer	Modular Jack Mobile phone battery connector
		wave; hand				
C	solder	reflow	No Pb	HDT/Tmelt too low	change plastic	No representative product found
		wave; hand				Sub D, 9 pos, vertical Sub D, 9 pos. right angle
D	solder	reflow	SnPb	HDT/Tmelt too low	change plating layer and plastic	Not found
		wave; hand				Modular Jack Mobile phone audio connector
E	solder	reflow	No Pb	HDT/Tmelt uncertain resp. to process temperature	heat resistance test	No representative product found
		wave; hand				No representative product found
F	solder	reflow	SnPb	HDT/Tmelt uncertain resp. to process temperature	heat resistance test change plating layer,	Mobile phone desk top plug Flex foil connector
		wave; hand				No representative product found

Table 1, Product categories

2.4. Limitations of the category concept

The following problems were met when working with the category-concept:
For certain categories, no representative part numbers could be found. Considering the size of the total product portfolio this does not mean that they do not exist. During the work it became clear that, in addition to the materials, the design / construction of the product has a decisive influence on its performance under 'leadfree' processing conditions.

3. Solder products

3.1. Test program

3.1.1. Solderability test

The solderability of a part depends in the first place on the wetting behaviour of the combination of plating layer and base material, the geometry of the solder contact has an influence but is of secondary importance.

For SMT parts and preferred for other: wetting balance test according to:
IEC 68-2-69 "Solderability testing of electronic components for surface mount technology by the wetting balance method". Indicator for solderability is the wetting force when the solder leg of the sample is immersed in a molten solder globule , as shown in fig.1.

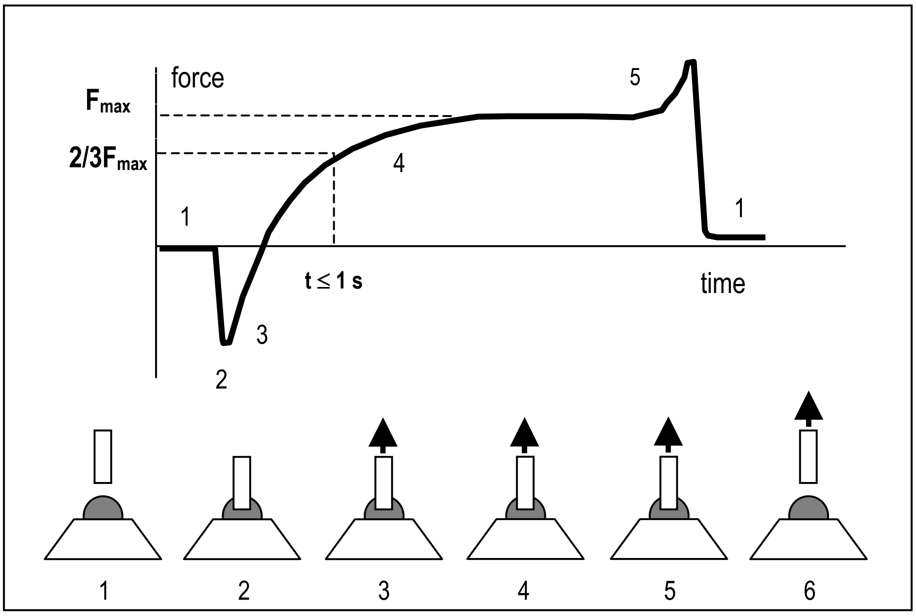

Figure 1, Globule wetting balance test.

For this test the conditions were adopted as required by Nokia:
Solder type: Sn (3.5-4.0)Ag (0.5-0.9)Cu
Flux: Actiec 5 (mildly activated flux acc. to IEC).
Solder temperature: 250°C±3°C

Test criterion: A wetting force of 2/3 F_{max} must be reached in 1.0 s or less.

Results
100% satin-bright Sn on CuSn4, passes this solderability test, as indicated by the results in table 2, obtained on pnr. 188277 (MicroMatch):

time to 2/3 F_{max} (sec)	
0.725	0.483
0.392	0.636
0.398	0.677

Table 2, Results of wetting balance test

The wetting curves are given in fig.2

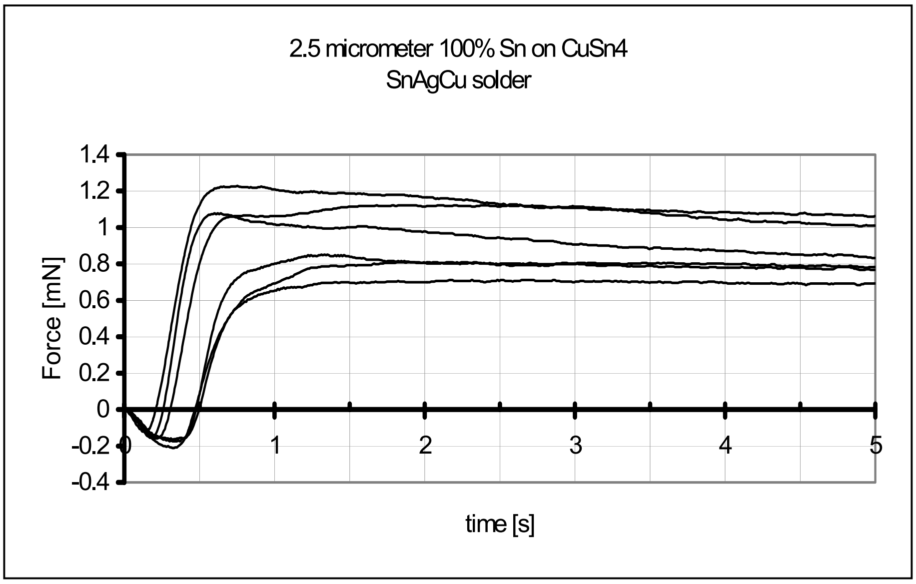

Figure 2, Wetting times for SnAgCu solder on pure Sn.

3.1.2. Whiskers

For this project a commercially available "whiskerfree" pure tin was chosen. It is claimed that these "satin-bright' finishes only produce "harmless" whiskers, i.e. very short, and growing extremely slowly, so that they never reach a length at which they can touch other part and cause problems. During the project it became clear that, contrary to the indications given by the supplier of the plating bath, whiskers were found on the samples. This was discussed with the vendor who announced a new bath, improved on this point.

Note:

The improved bath formulation has become available since the first edition of this report. It was tested and found to fulfill the conditions for "freedom of whiskers" as adopted by Tyco Electronics:

- no whiskers longer than 50 µm in length,
- no whisker density greater than 10 whiskers per mm^2.

As such it was added to the list of plating solutions approved by Tyco Electronics for Pb-free applications. The new tin plating can pass the whisker test as a direct coating onto copper; however, for many of our products, the presence of a Ni-underlayer is an extra safeguard against the occurrence of whiskers.

3.1.3. Resistance to soldering heat

3.1.3.1. Surface mount parts

The parts were subjected to a reflow temperature profile, based on a test conditions published by Philips, Infineon and STMicroelectronics [2]. For details see table 3 and figure 3. Since the preferred equipment for such tests, a hot-air reflow oven is not available, a similar profile was developed for the available infra-red oven.

	Tyco Elect NL	*Philips (ref.)*
preheat slope 125ºC to 220ºC (ºC/s)	0.58	*0.4 to 1.0*
time for T=125ºC to 220ºC (s)	163	*150 to 210*
time at T > 220ºC (s)	75	*60 to 90*
time at T > 250ºC(s)	22	*10 to 30*
T peak(ºC)	260	*260 -5/+0*
max. cooling rate for T=250ºC to160ºC (ºC/s)	3.5	*6*
time for T=25ºC to peak (s)	285	*240 to 360*

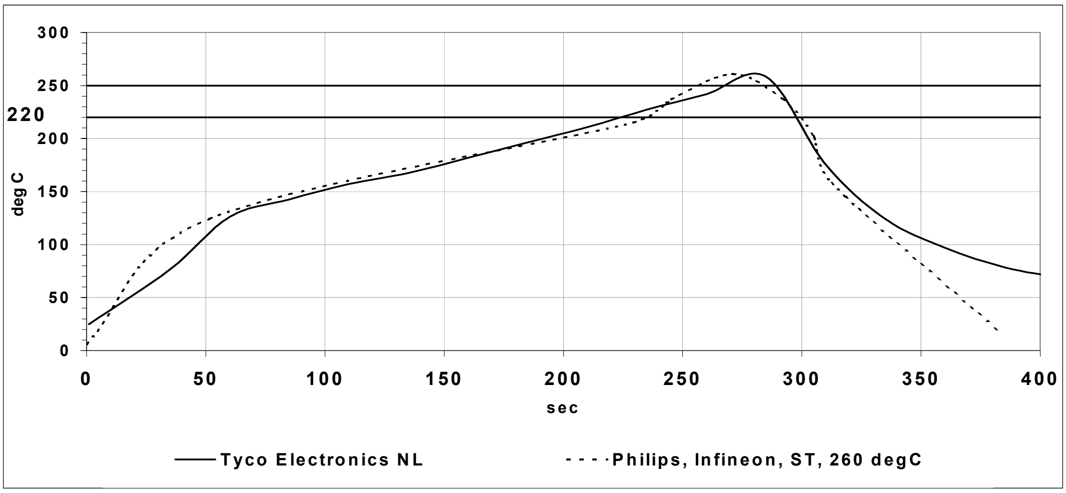

Table 3 Reflow profile data
Figure 3, Reflow temperature profile as used in tests and reference profile.

Cat	partnumbers tested:	plastic	results
A	SIM card connector	LCP	No visible damage
B	Mobile phone battery connector	LCP	No visible damage
	Modular Jack	Nylon 4/6	No visible damage
F	Mobile phone desk top plug	LCP and Nylon 4/6	Minor changes Nylon 4/6 part, otherwise no visible damage. This may vary with reflow conditions.
F	Flex foil connector	Nylon 4/6	Bending of thin walls,

Table 4, Results of reflow oven tests.

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[2] "Temperature profile for the assessment of moisture sensitivity level (MSL) of lead-free semiconductor devices", Philips Semiconductors , Infineon Technologies, STMicroelectronics, July 16th, 2001.

3.1.3.2. Wave solder parts

The parts were dipped in molten solder, to simulate the passage through a solder wave. Conventional SnPb solder was used, but at a temperature for leadfree solder.
T solder: 280 ºC.
Note: this is the highest solder temperature obtained from literature and conversations with soldering specialists.

Immersion time: 5 s initial, then progressively shorter as indicated below.

Immersion depth: length of the solder termination which protrudes below the pcb.

Visually check plastic of housing for signs of deterioration, in particular local melting.

In case of visual deterioration, reduce immersion time by 1 second.
Repeat this procedure until no deterioration is visible, then if possible measure holding force.

Cat	partnumbers tested:	plastic	results	Comments
D	Modular Jack	PBT	Visible damage to locking of contact in housing after 2 s	Further study of design influence recommended
C	Sub D, 9 pos, vertical	PBT	Visible damage to locking of contact in housing after 4 s. Loss of contact locking force, see figure 4 below	Further study of design influence recommended
C	Sub D, 9 pos. right angle	PBT	No visible damage	
D	Mobile phone audio connector	LCP, Lexan	Melting of Lexan bottom part after 2 sec	Check of hand soldering conditions recommended

Table 5, Results of wave solder tests.

With wave solder parts, a great influence of the product design was seen and it is not possible to generalize.
The damage observed was mostly to the fixation of the contact in the housing, the degree of damage varying with the shape of the solder leg.

Some examples:

- A thin short lead will heat up quickly(small heat capacity). The shorter it is the faster the heat will reach the plastic and cause damage. This is for instance the case for the Modular Jack in category D. See figure 4

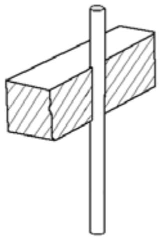

Figure 4

- A wide fixation area has a larger heat capacity, which forces the heat to spread over a larger area. This results in a lower temperature and less damage to the plastic. Although there may be less visible damage to the plastic, the holding force of the contact in the housing can be significantly reduced after only a short soldering. A typical example, Sub D, 9 pos, vertical, cat C is shown in figures 5 and 6 below.

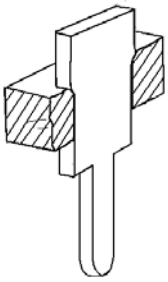

Figure 5

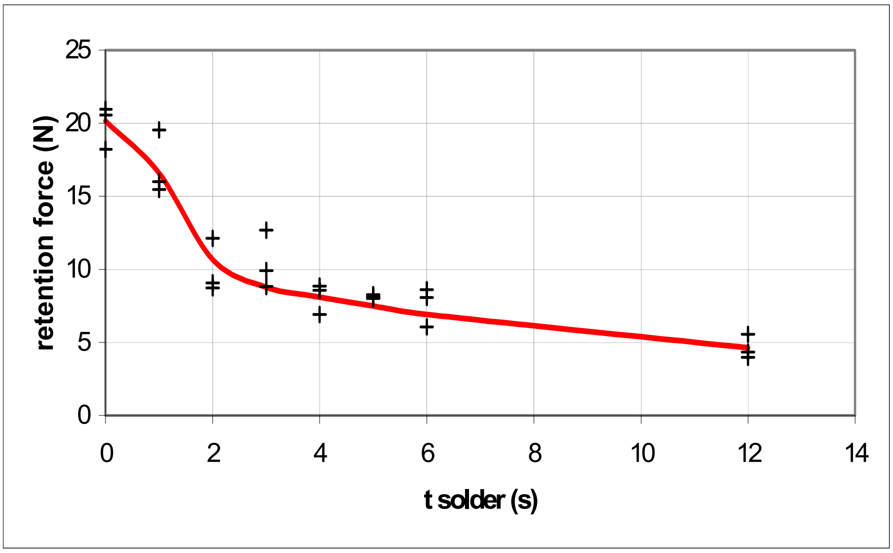

Figure 6, Loss of retention force with solder time

- This heat spreading effect is even stronger with design shown in fig. 7. After 12 s immersion in solder of 280°C, there was no visible damage. Here the solder lead protrudes sideways from the retention area, which apparently inhibits the flow of heat from the solder leg to the retention area.

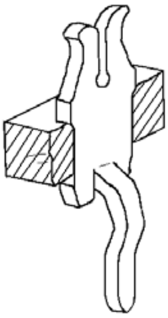

Figure 7

Further investigation of these effects is necessary to develop design rules for leadfree products.

4. Press-fit products

The lead-free plating on the press-in terminations was the same commercially available "satin bright" whiskerfree pure tin as used for the solder contacts. As reference, the existing SnPb-plating on the terminations was tested under the same conditions.
The platings of the plated-through holes include different kinds of lead-free plating, as well as conventional SnPb plating to check compatibility with the existing PCB's.

4.1. Overview of the tests

Testgroup B (according IEC60352-5) on minimum and maximum holes.
Measurement of press-in force. Press-in speed: 25mm/min,
24 hrs recovery,
Measurement of push-out force. Push-out speed: 3mm/min,
2 repair operations each with measurement of press-in and push-out force.

Testgroup C (according IEC60352-5) on minimum, nominal and maximum holes.
Contact resistance
Rapid change of temperature
Climatic sequence
Dry heat
Flowing mixed gas corrosion test
Contact resistance

4.2. Press-in terminations

Different press-in terminations types are in use within Tyco Electronics. The termination types given in table 6, were tested. These cover the majority of the pressfit products in the Tyco product portfolio.

Termination type	Diameter of finished plated-through hole	Products
Action pin for 0.6	0.6mm(0.55…0.65)	Z-Pack HM (Compact PCI)
Eye of the needle for 0.7	0.7mm (0.65…0.80)	Z-Pack FB+
Action pin for 1.0	1.0mm (0.94..1.09)	Eurocard
Eye of the needle for 1.0	1.0mm (0.94..1.09)	Sipac, Eurocard receptacles
Multispring for 1.0	1.0mm (0.94..1.09)	Sipac, Eurocard headers

Table 6, Types of press-in terminations tested

4.3. PCB's

The following PCB's wereused for the test (25µm-50µm Cu underplate is used on all PCB's)

HAL SnPb	max 35µm SnPb
Galvanic Au	4-5µm Ni + 0.1-0.5µm Au
Cu+OSP	0.2-0.5µm OSP (Entek+)
Immersion Sn	0.5µm min
Immersion Au	4-5µm Ni + 0.1-0.5µm Au
Immersion Ag	0.1-0.15µm min

Table 7, Types of PCB's tested

To test according to the IEC-specification minimum, nominal and maximum holes are required. A deviation of 0.05mm in the drilled holes covers the worst case situations. Table 8 below gives the typical drilled and finished plated-through hole diameters for the different PCB platings.

	∅0.6		∅0.7		∅1.0	
	min∅	max∅	min∅	max∅	min∅	max∅
Drilled holes	*0.65*	*0.75*	*0.75*	*0.85*	*1.05*	*1.15*
HAL SnPb	0.55	0.64	0.65	0.74	0.95	1.05
Galvanic Au	0.55	0.65	0.64	0.74	0.94	1.04
Cu+OSP	0.55	0.64	0.65	0.73	0.94	1.05
Immersion Sn	0.56	0.65	0.65	0.75	0.95	1.05
Immersion Au	0.56	0.66	0.66	0.76	0.95	1.06
Immersion Ag	0.57	0.66	0.66	0.76	0.95	1.06

Table 8, Plated-through hole diameters tested.

4.4. Test results

At the time of this report, only testgroup B for maximum holes has been for:
∅0.6 mm action pin and ∅0.7 mm eye of the needle.
The remaining of testgroups B and C will be completed by the end of May.

The insertion and retention forces of the leadfree contacts are +/- 10% higher than with SnPb due to a higher friction between the contact and the hole.

Galvanic Au and Cu+OSP are very popular with some customers as lead-free solutions, but can cause problems due to lower retention forces.

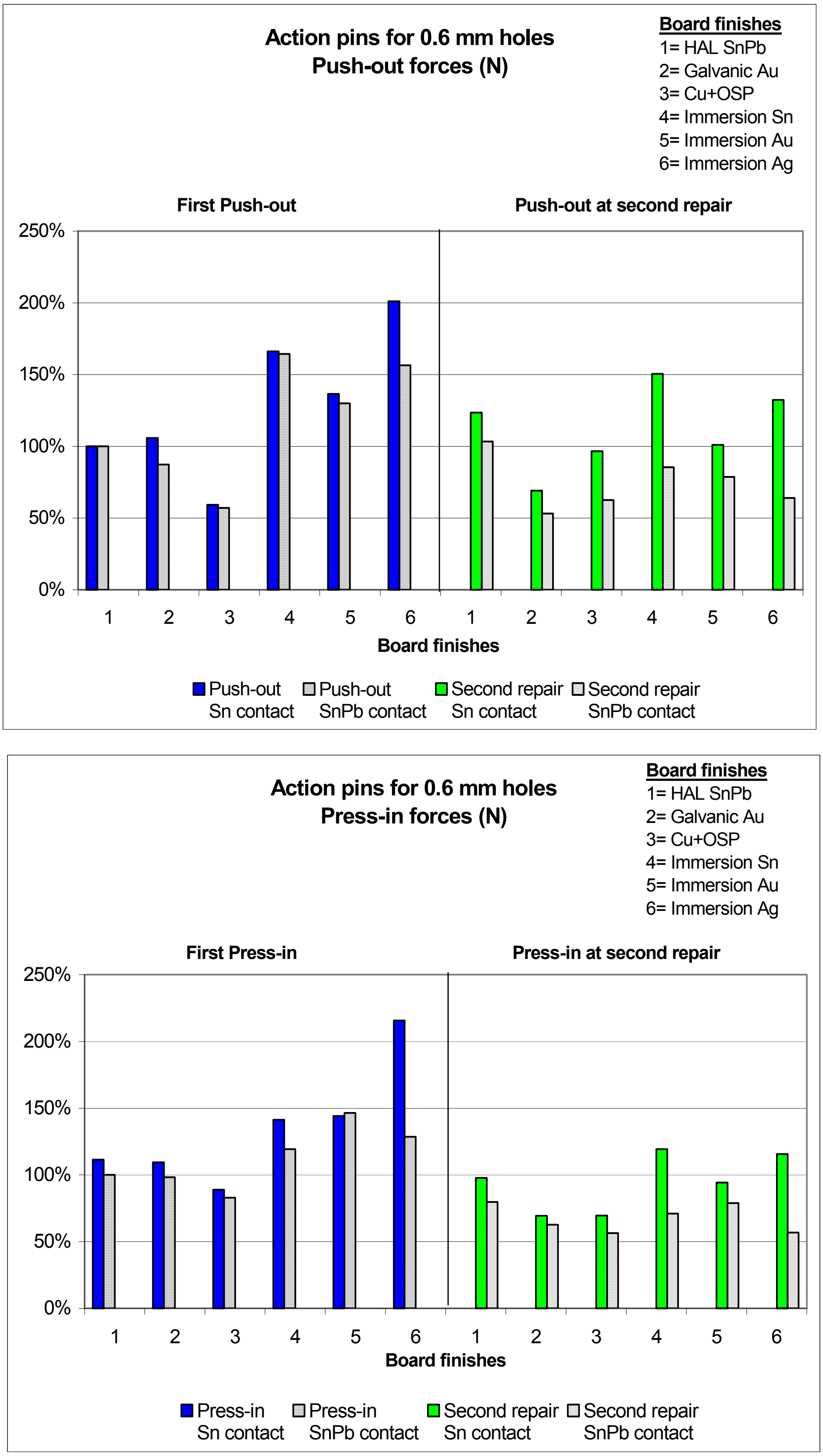
Action pins for 0.6 mm holes
Push-out forces (N)
Board finishes
1= HAL SnPb
2= Galvanic Au
3= Cu+OSP
4= Immersion Sn
5= Immersion Au
6= Immersion Ag
First Push-out
Push-out at second repair
250%
200%
150%
100%
50%
0%
1
2
3
4
5
6
1
2
3
4
5
6
Board finishes
Push-out Sn contact
Push-out SnPb contact
Second repair Sn contact
Second repair SnPb contact
Action pins for 0.6 mm holes
Press-in forces (N)
Board finishes
1= HAL SnPb
2= Galvanic Au
3= Cu+OSP
4= Immersion Sn
5= Immersion Au
6= Immersion Ag
First Press-in
Press-in at second repair
250%
200%
150%
100%
50%
0%
1
2
3
4
5
6
1
2
3
4
5
6
Board finishes
Press-in Sn contact
Press-in SnPb contact
Second repair Sn contact
Second repair SnPb contact

Fig. 8

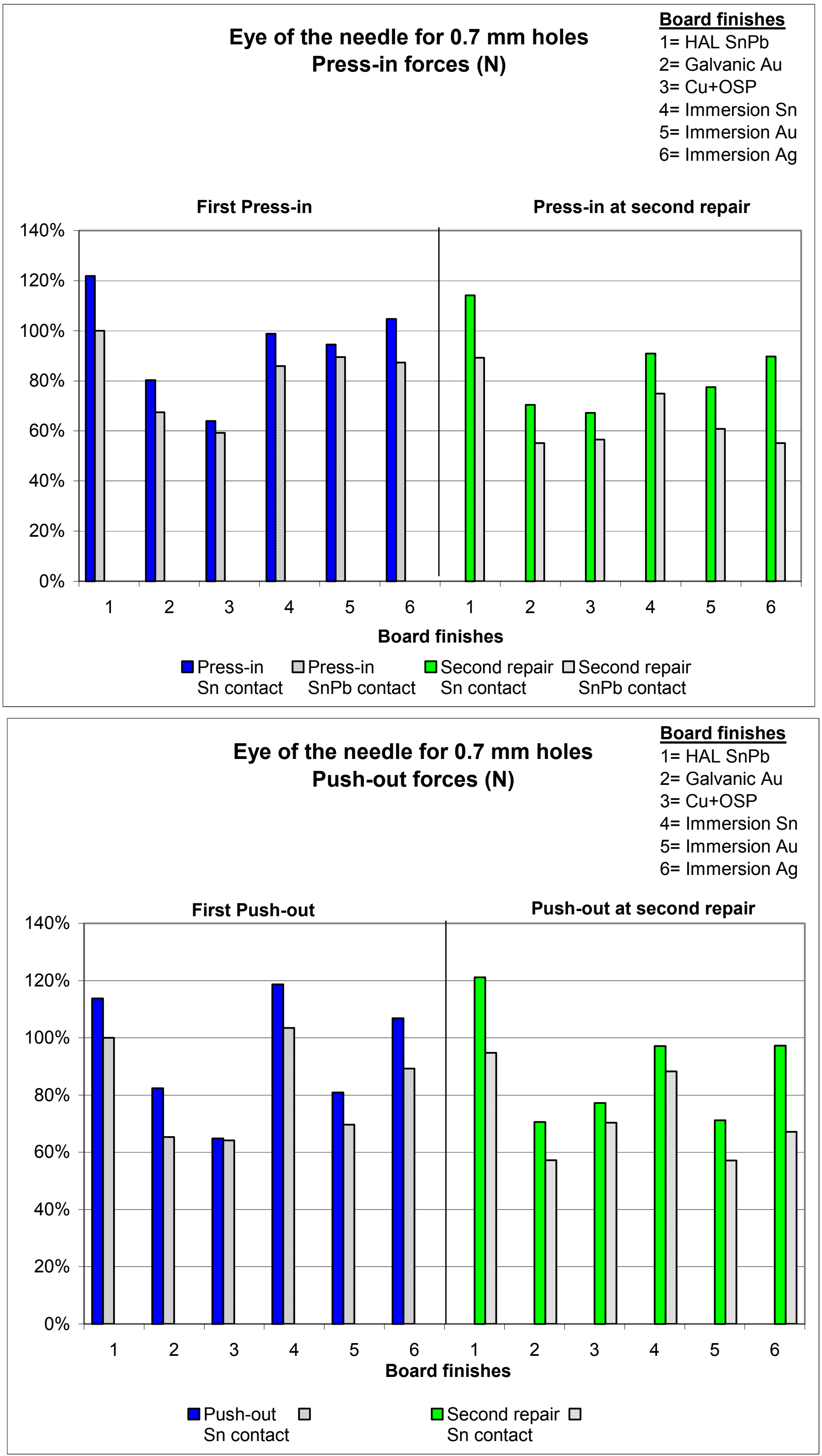
Eye of the needle for 0.7 mm holes
Press-in forces (N)
Board finishes
1= HAL SnPb
2= Galvanic Au
3= Cu+OSP
4= Immersion Sn
5= Immersion Au
6= Immersion Ag
First Press-in
Press-in at second repair
0%
20%
40%
60%
80%
100%
120%
140%
1
2
3
4
5
6
1
2
3
4
5
6
Board finishes
Press-in Sn contact
Press-in SnPb contact
Second repair Sn contact
Second repair SnPb contact
Eye of the needle for 0.7 mm holes
Push-out forces (N)
Board finishes
1= HAL SnPb
2= Galvanic Au
3= Cu+OSP
4= Immersion Sn
5= Immersion Au
6= Immersion Ag
First Push-out
Push-out at second repair
0%
20%
40%
60%
80%
100%
120%
140%
1
2
3
4
5
6
1
2
3
4
5
6
Board finishes
Push-out Sn contact
Second repair Sn contact

Fig. 9

5. Conclusions

Product categories based on materials information only are insufficient to assess the compatibility of a part with leadfree soldering.

The part geometry is a major factor of influence which varies independently of the material categories. More work is needed to develop design rules for leadfree products, which take proper account of this. Special attention should be given to the heat transfer in wave solder products.

As a result of the above, the compatibility of a part with leadfree soldering should be assessed on a case-by-case basis by the responsible Product Engineer.

For pressfit it may be expected that certain specific combinations of press-in termination types and leadfree PCB-finishes will be classified as not recommendable.
Minimum retention force requirements may be difficult to meet and/or to quarantee over the product lifetime. A redesign of the PCB-hole, the termination type or both may be unavoidable.

For more information please contact
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