Hot Air Solder Leveling in the Lead-free Era

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Abstract
Although the advantages of Hot Air Solder Leveling (HASL) in providing the most robust solderable finish for printed circuit boards are well recognized, in the years leading up to the implementation of the EU RoHS Directive in July 2006 the conventional wisdom was that it would have no place in the new lead-free electronics manufacturing technology. The widely promoted view was that HASL, which had been the most popular printed circuit board finish in North America, Europe and most of Asia outside Japan during the tin-lead era, would be largely replaced in the lead-free era by Organic Solderability Protectants (OSP) and immersion silver with perhaps a minor role for immersion tin. This view was reinforced by some early trials of lead-free HASL in which the tin-silver-copper alloy, then promoted as the universal lead-free replacement for tin-lead, was used as the coating alloy. The aggressive dissolution of copper by that alloy and its non-eutectic behavior made it difficult to use and to get satisfactory results. In the meantime, however, in Europe a microalloyed tin-copper alloy with low copper dissolution and eutectic behavior was evaluated and found to yield promising results. A smooth mirror-bright finish could be achieved on existing equipment with process temperatures that existing laminate materials could accommodate. An unexpected advantage was that the thickness of the lead-free HASL finish was more uniform than typically obtained with tin-lead so that it could be used in applications previously excluded to tin-lead HASL because of concerns about coplanarity, e.g. pads for BGA, CSP and fine pitch QFP. By July 2006 there were nearly 200 lead-free HASL lines running in Europe and that number has continued to increase since then. In response to demand by European customers many Chinese printed circuit board shops have installed lead-free HASL and there are now lines operating in South East Asia, India and North America. As problems have been encountered with OSP and immersion silver finishes electronics manufacturers have looked to lead-free HASL as a solution. In the more than 5 years in which the lead-free HASL process has been used in commercial mass product much has been learned about the operation of the process on the optimization of results. In this paper the author will report on current best practice on the operation of lead-free HASL lines and the properties that can be expected of a properly applied lead-free HASL finish.

Introduction
The wisdom traditionally expressed by advocates of the hot air solder leveled (HASL) finish when the solder used was a tin-lead alloy, "nothing solders like solder" remains equally valid in the lead-free era. A strong case can be made that when properly applied a HASL finish provides a printed circuit board with the most robust guarantee of solderability currently available. However, the statement that "nothing solders like solder" requires some expansion.

A fundamental requirement of a solder joint is metallurgical continuity between the copper pad of the printed circuit board and the termination of the component (Figure 1). Components terminations can have a wide variety of metallurgies that create issues that are beyond the scope of this paper so that all that will be considered here is that part of the solder joint that is the connection to the printed circuit board. For the current conventional technology that pad is electrodeposited copper so the short form justification for a HASL finish could be stated more fully as "nothing solders like *copper that has been pre-wetted with* solder".

That statement of the key advantage of HASL is more technically correct because what this finish delivers is not so much the solder that is visible but the wetted interface that lies beneath the surface of that solder at its interface with the copper. Because, when a tin-containing solder wets copper an intermetallic compound, Cu_6Sn_5, forms almost instantaneously, the evidence that wetting has been achieved is provided by the presence of that interfacial intermetallic compound (Figure 1). Thus a short form characterization of the benefits of the HASL finish could be that "half the solder joint has already been made".

The term used to describe the ease with which solder, with the help of an appropriate flux, can wet a substrate is "solderability". With wetting already established the HASL finish delivers solderability unequalled by any of the alternative printed circuit board finishes that do not contain tin. The additional benefit not mentioned in any of the foregoing characterizations of the HASL finish is that when properly applied it can preserve solderability for a very long period of time without the need for additional protection from the environment or special storage conditions. There are many anecdotal reports of printed circuit boards with a HASL finish soldering easily after many years of uncontrolled storage[1].

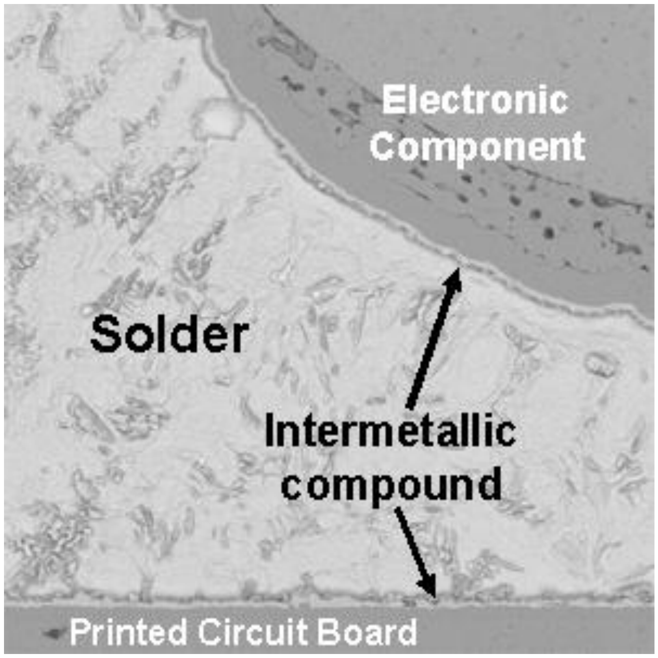


Figure 1. The essential features of a solder joint that provide metallurgical continuity

The Place of HASL in PCB Finishing

Until the electronics industry was forced by the EU RoHS Directive[2] to consider the prospect of eliminating lead tin-lead eutectic solder (nominally Sn-37Pb) applied by the HASL process was the most widely used (in terms of the area of panels processed) printed circuit board finish in North America and Europe[3]. HASL was also widely used in Asia but the market share was smaller because of the dominance in those markets of consumer electronics. For the consumer electronics industry the short time between manufacture and soldering that resulted from the effective application of "Just in Time" inventory management systems meant that the solderability of copper pads could be satisfactorily ensured with an OSP finish.

In the period leading up to the implementation of the RoHS Directive in July 2006 the view that was most widely expressed was that the HASL finish would disappear as the industry moved to lead-free technologies[4]. The justification for this prediction was problems with the HASL process that were claimed to include:

- Damage to the printed circuit board by the additional thermal excursion (Figure 2)
- Coplanarity problems caused by pad to pad variation in the coating thickness (Figure 3)
- Stencil gasketing problems during paste printing associated with the variation in coating thickness and "mushroom cap" profile of the coating on small pads (Figure 4)
- The heat and fumes associated with the process that were considered out of place in a modern PCB shop

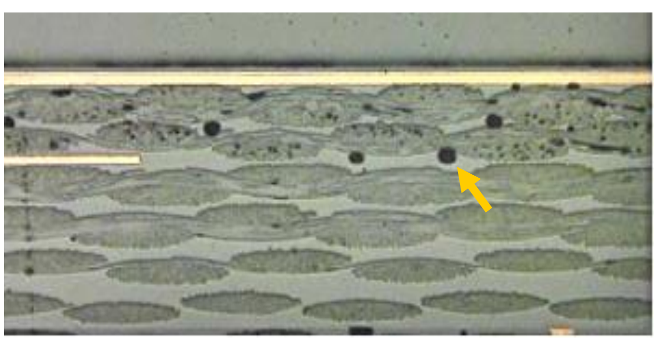


Figure 2. Voids in laminate resin due to excessive exposure to heat

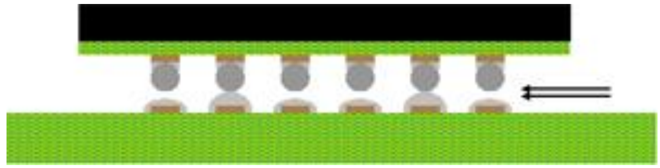


Figure 3. Potential coplanarity issue with a HASL finish

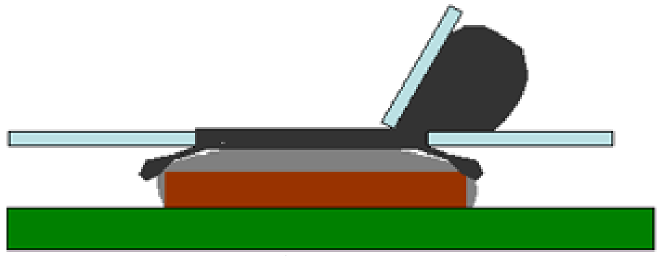


Figure 4. Paste bleed due to problem of stencil gasketing on non-planar HASL coating

In practice these potential problems have not been realized to the extent expected and lead-free HASL has been in widespread use, initially in Europe, since 2002 with many millions of boards processed successfully soldered and put into long term service. Data collected by the author's company indicates that there are more than 400 lead-free HASL lines currently in commercial production around the world with more being commissioned every month to meet the growing demand. This number has grown by 45% since the last quarter of 2006. To have achieved that growth an average of more than five new lines would have been commissioned each month and that number is consistent with the practical experience within the industry over that period. More than half of these lines are in Europe but about a quarter are now in China as the volume of boards ordered with this finish by European and American OEM increases.

Unless the panel is passed through the HASL process more than twice and/or a solder temperature higher than necessary is used the expected damage to the laminate has not been observed even with CEM-1, CEM-2 and FR-2 grades of laminate. The likelihood of damage is being further reduced as more heat-resistant grades of laminate are introduced to accommodate other requirements of lead-free processing.

The variation in the solder coating thickness of a properly applied lead-free HASL finish is typically about half that of the tin-lead HASL finish it replaces. And the coplanarity has been found to be good enough for the finish to be used on boards with large area array components.

And on the issue of heat and fume modern HASL lines have been designed to provide operating conditions consistent with those of any other equipment in a modern printed circuit board shop (Figure 5).

Figure 5. Modern automatic in-line horizontal HASL line (photo courtesy Cemco/FSL Ltd)

HASL Alternatives

If the problems attributed to the HASL process were indeed the reason for not using this finish it would have disappeared long before the implementation of lead-free since the printed circuit board finishes now promoted on the basis of their being lead-free, OSP, immersion silver, immersion tin and electroless nickel/immersion gold (ENIG) were already available. While all of these finishes found some application prior to the need to eliminate lead from electronic assemblies the HASL finish maintained its dominant market share.

All of the mentioned alternatives offer a degree of coplanarity that cannot be matched by even the best HASL finish but the process maintained its dominance because none of the alternatives offer a solution that is problem-free. For many applications HASL offers the best compromise particularly when robust solderability is the main requirement.

The protection that can be provided by the thin organic film of the *OSP* finish, albeit chemically bonded to the copper, is limited particularly under conditions of heat, humidity and air pollution. Even if solderability is good enough for the first stage of reflow with enough surviving to the second stage of reflow, if a final stage of wave soldering is required it is often difficult to meet barrel fill criteria.

The *immersion silver* finish dissolves during the soldering process so that all it can do is provide protection from oxidation for the underlying copper. The solderability of the boards with this finish is therefore dependent on the quality of preparation of the copper before the application of the finish and so is vulnerable to variation in the control of the pre-etch process. Since the deposit is formed mainly by a chemical displacement process the thickness of the coating and hence the degree of protection that it can provide is limited. Although it is claimed not to affect solderability the silver is vulnerable to tarnishing in polluted atmospheres. Additional coatings can be applied to prevent tarnishing if there is concern about the cosmetic appearance of the board but in any case it is generally recommended that boards with an immersion silver finish be stored in sealed packaging.

As a consequence of its successful promotion immersion silver has enjoyed the status of the preferred lead-free finish in the US market and so has been exposed to a wider range of operating conditions than had been the case before lead-free implementation. One phenomenon to emerge from that experience is catastrophic "creep corrosion". This phenomenon occurs when the assembled board is exposed to humid atmospheres polluted with sulfur and is driven by the electrochemical cell set up between the silver and the small areas of copper inevitably exposed near the edge of the solder resist on solder mask defined pads[5].

The *immersion tin* process matches the HASL process in forming a layer of intermetallic at the tin-copper interface although by solid state diffusion rather than by reaction with molten solder. Unlike immersion silver it is not vulnerable to tarnishing and does not need special storage. However, as with immersion silver the deposit is formed by a chemical displacement process so that the thickness is limited. The intermetallic layer continues to grow in storage and can completely consume the tin with consequent loss of solderability. The growth rate of the intermetallic is greatly accelerated during a thermal excursion so that solderability problems can be encountered in the second stage of double-sided reflow or in a final stage of wave soldering.

As well as being perfectly flat the *electroless nickel/immersion gold* finish is hard and sufficiently wear resistant for use on edge connectors that require only a limited number of insertion/withdrawal cycles. This finish can also accept wire bonding. The finish delivers excellent solderability and high reliability joints in the great majority of cases but confidence in the finish has been damaged by a small but persistent incidence of catastrophic joint failures associated with the phenomenon known as "black pad". A further complication is that the phosphorus that is an unavoidable constituent of the electroless nickel deposit can react with the tin, copper, and silver that are the common constituents of lead-free solders to form at the solder/substrate interface complex intermetallic compound that make the joint vulnerable to impact loading. The gold dissolves quickly in molten solder so that the joint is formed by wetting of the underlying nickel so that the solderability of the finish is ultimately determined by the quality of that nickel surface. As the product of a chemical displacement process the gold coating is very thin so that the protection that it can provide to the underlying nickel is limited and very dependent on process control. The very good solderability of freshly etched nickel can be quickly lost if the immersion gold finish does not have the integrity to protect it from oxidation.

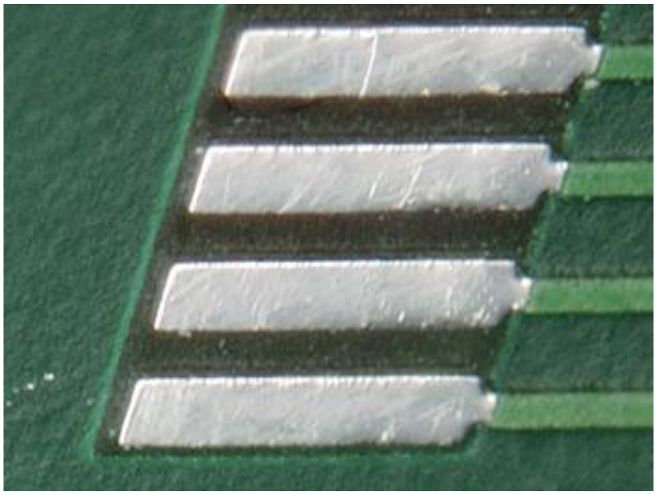
Characteristics of a HASL Finish

Because, as explained earlier, a HASL finish is in a way already one half of a solder joint the visual criteria for quality are essentially the same as for a solder joint. The surface should be smooth and bright with no evidence of non-wetting or dewetting (Figure 6). In cross-section the ideal finish would look something like that in Figure 7 with the features highlighted in the schematic diagram of Figure 8.

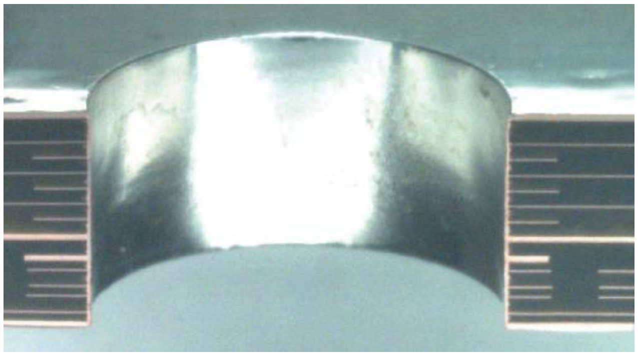
It is clear from the cross-section that surface tension plays a major role in determining the profile of the finish with a characteristic “mushroom cap” tending to form on a defined area with the coating stretched thinner at corners.

The main thing that can go wrong with the finish is for there to be areas where the coating is too thin (Figure 9)   This problem is a sign that the coating has not properly wetted the copper substrate or that there was not enough solder left on the pad to maintain a stable film over the whole area. Whatever the cause in the areas where the solder coating is not sufficient to fully cover the intermetallic layer there will be a high probability of non-wetting and/or dewetting in subsequent soldering processes.

(a) CSP Pads



(b) QFP pads



(c)   Through hole

Figure 6. Typical lead-free HASL finish

Figure 7. Cross-section of an ideal HASL finish

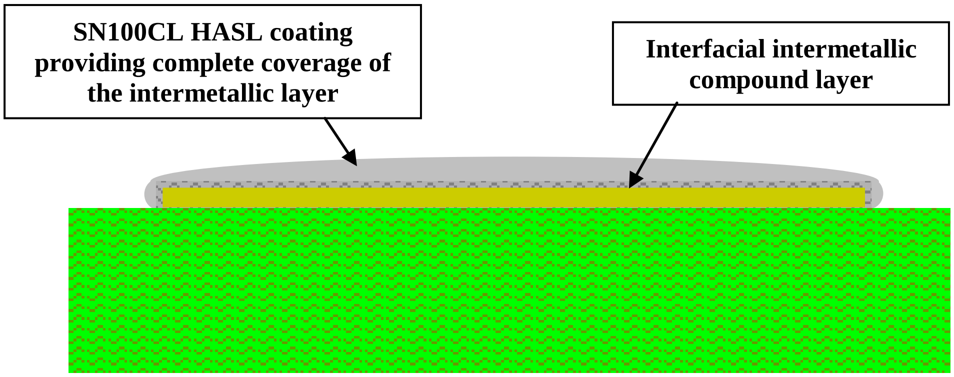
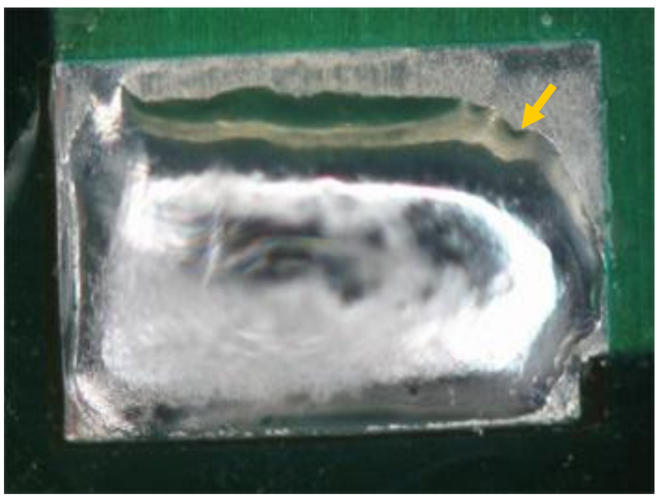
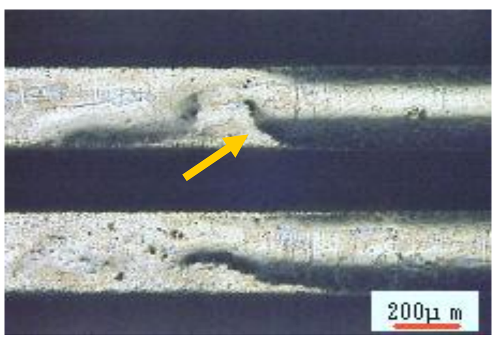


Figure 8. Schematic representation of the cross section of an ideal HASL finish



(a)



(b)

Figure 9. Dewetting of the solder coating

There are several reasons why satisfactory wetting might not be achieved:

- The copper surface was not prepared to the point where complete wetting (with no subsequent dewetting) could be achieved with the flux used with the solder temperature and contact time to which the panel was exposed during the HASL process.

- The adjustment of the hot air knives was such that not enough solder was left on the pads to permit full coverage of the pad surface under the influence of surface tension forces.

If the solder coating is not sufficient to provide a layer of free, unreacted solder over the intermetallic layer solderability is quickly lost. Although the presence of the interfacial intermetallic provides confirmation that wetting has occurred the intermetallic loses solderability when exposed to the atmosphere.

When such problems are noted the solution can usually be found simply by taking the countermeasures implied by the foregoing diagnoses.

The Lead-free HASL Process

One of the advantages of the HASL process is its simplicity. The cleaned and fluxed printed circuit board is brought into contact with molten solder for sufficient time to achieve wetting and then excess solder is blown off with air knives- planar jets of air at a temperature above the melting point of the solder. When the solder coating has solidified the board is passed through a washer to remove flux residues and dried. Air cooling ensures the smoothest brightest finish and for the favored SnCuNiGe nothing is gained in regard to minimization of the intermetallic thickness by water or oil quenching.

It is immediately apparent from visual inspection whether the process has been successful but XRF techniques and/or cross-sectioning can be used to check the coating thickness and the quality of wetting.

In the vertical process (Figure 10) a panel of boards is manually mounted on a frame which moves vertically downward into the solder bath, holds for an optimized immersion time, typically 2-3 seconds, and then raises the panel through the operating air knives that are adjusted to clear through holes and vias while leaving an adequate thickness of solder on all areas where a solderable finish is required. The board is removed from the jig as the solder cools and solidifies and placed on the conveyor of the washer/dryer. The operator can quickly inspect for finish quality during this handling.

The great majority of HASL lines are of vertical design and quite capable of applying the finish to a high quality standard. Although most lines require manual loading and unloading of the panel fully automated vertical lines are available that can deliver rack-to-rack performance incorporating fluxing and preheating and subsequent washing and drying.

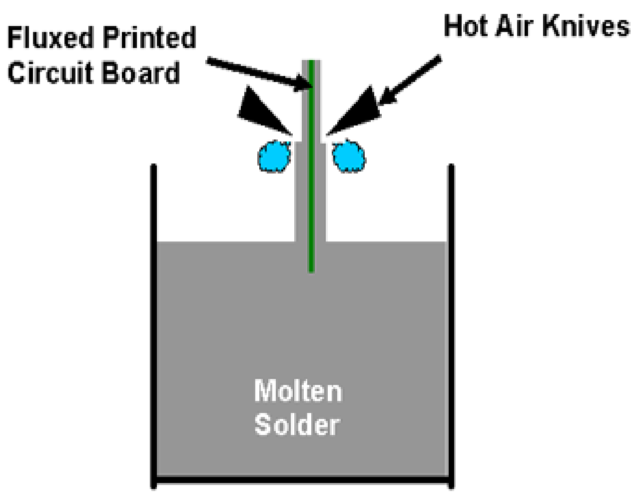


Figure 10. Schematic representation of the vertical HASL process

The principle is similar in the horizontal process but instead of the board being immersed in a bath of solder it is flooded with solder applied through nozzles or between rollers on the top and bottom of the panel before being passed between hot air knives located above and below the board. Because it is an in-line process horizontal HASL can be easily integrated with other in-line processes from the pre-etch to washing and drying to create a continuous line such as that in Figure 5. With the in-line preheating stage the time required for exposure to solder can be reduced to a matter of a fraction of a second with a corresponding increase in per hour throughput.

The horizontal process has an advantage in that the finish is more uniform in thickness. In the vertical process there is a tendency for the solder to move toward the lower edge of the pad under the influence of gravity whereas in the horizontal process gravity has no effect on the distribution of the solder over the surface.

Lead-free HASL Alloys

As in other processes involving solder, the tin-lead eutectic is the benchmark against which other solders are judged. The Sn-37Pb alloy can deliver a HASL finish that is smooth and bright and reasonably even and there is no doubt that it is the eutectic character of the tin-lead that is the major factor in making that possible. Because of the way it solidifies in a single stage with a sharply defined melting point a eutectic has high fluidity close to its melting point and does not suffer from the shrinkage effects that detract from the appearance of the finish left by alloys that exhibit non-eutectic behavior.

It is not a coincidence, therefore that the solder most widely used in the lead-free HASL process is also the only lead-free alloy that comes close to matching the eutectic behavior of the Sn-37Pb. That alloy is based on the tin-copper eutectic but with an addition of nickel at a specific level that promotes eutectic behavior[6] (Figure 11). This alloy also incorporates an addition of germanium to control oxidation in the liquid and solid state.

This SnCuNiGe alloy has two other properties that make it particularly suited to the HASL process, a low rate of copper dissolution and a stable interfacial intermetallic.

Since the copper pads of the printed circuit board are exposed to molten solder it is important that not too much copper is lost by dissolution during the process. The nickel addition that promotes eutectic behavior in the tin-copper eutectic also stabilizes the intermetallic layer that forms on the surface of the copper so that it acts as a barrier to further dissolution. Figure 12 shows the results of an experiment to compare the rate of dissolution of the SnCuNiGe alloy with the tin-lead benchmark and "SAC305", the Sn-3.0Ag-0.5Cu alloy that has been widely promoted as the default lead-free solder.

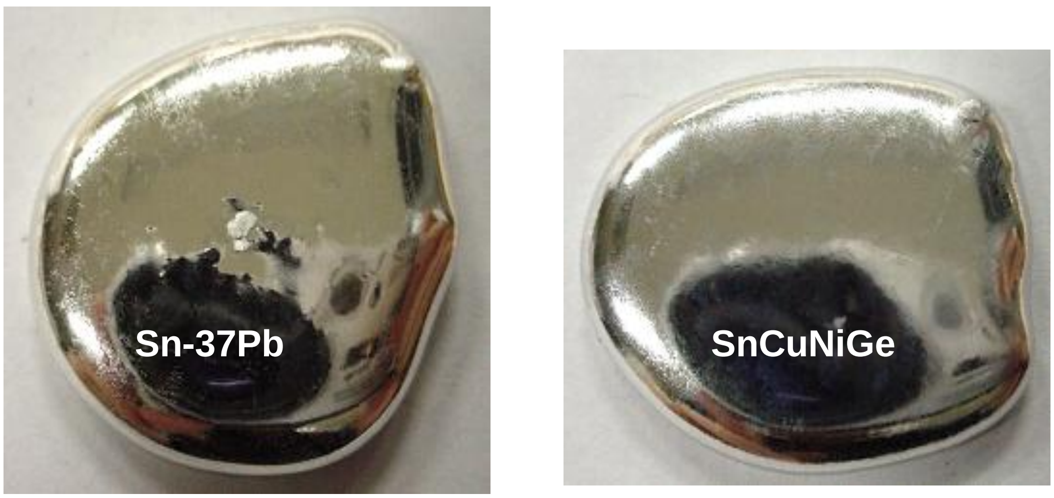


Figure 11. Comparison of the appearance of the SnCuNiGe alloy with Sn-37Pb

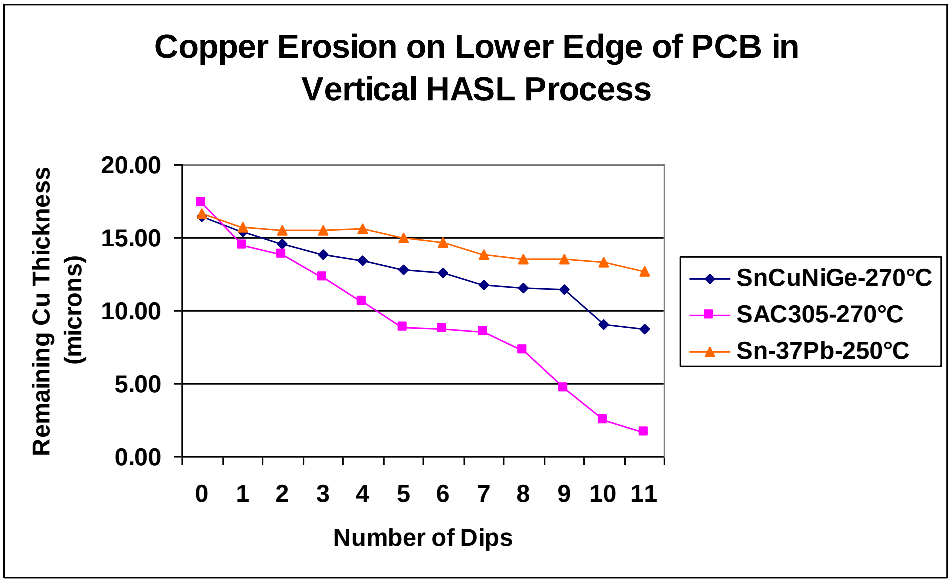


Figure 12. Comparison copper dissolution rates of HASL alloys

Even for a HASL finish that has been correctly applied the solderability is eventually lost when the intermetallic layer has grown to the point where it has consumed all the tin (Figure 13). The slow growth of the intermetallic layer (Figure 14) means that solderability is retained even through extensive thermal excursions.

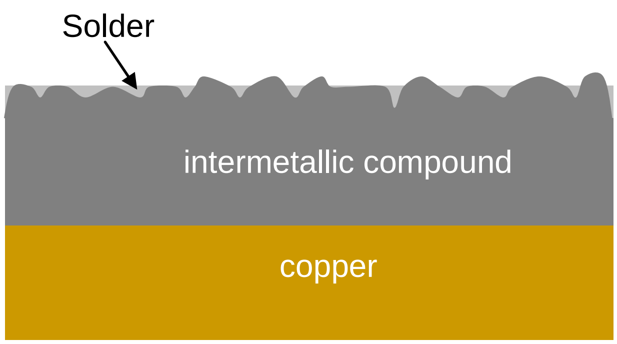
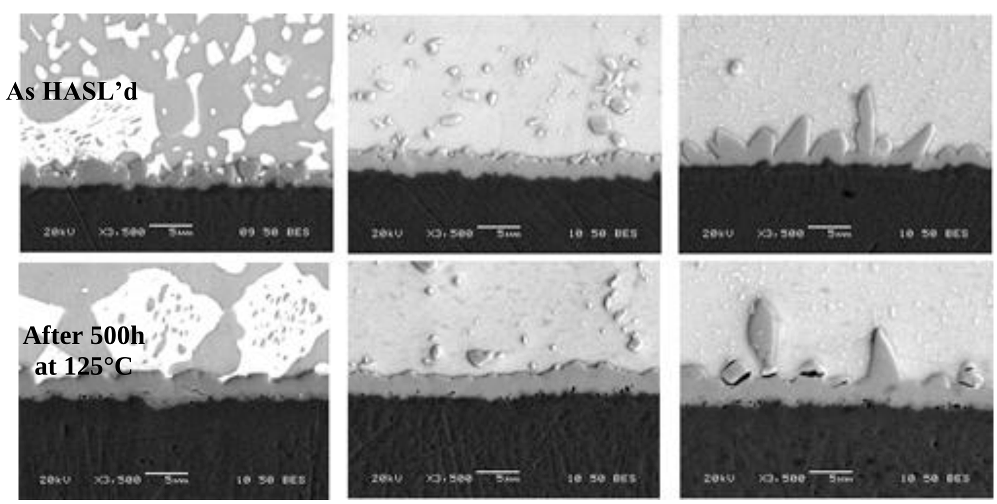


Figure 13. Solderability is lost when the intermetallic layer has grown through to the surface



Sn-37Pb **SnCuNiGe** **SAC305**

Figure 14. The nickel-stabilized intermetallic grows more slowly.

Equipment Requirements and Process Parameters

The lead-free HASL process has to operate within the constraint that applies to all lead-free processes- the melting point of the alloy is higher than that of the tin-lead solder that it replaces but because of limits on the temperature/time profiles to which some materials can be exposed process temperatures have to be kept as close as possible to those used with Sn-37Pb.

With a melting point of 227°C, 44°C higher than that of Sn-37Pb, this constraint means that the process window for lead-free HASL with the most widely used alloy is approximately halved to about 35-40°C. The main implication of this smaller process window is that temperatures have to be held much closer to the set point than needed to be the case for the tin-lead HASL process. Machine manufacturers have responded to this challenge by increasing heater capacity and insulation of the solder pot and upgrading temperature control.

The temperature that has to be reached for wetting of the copper to occur is much the same for lead-free solder as it is for tin-lead solder so the primary determinant of the process temperature is the heating rate required to get the surface of the board to the melting point in the shortest practicable time. The heating rate is proportional to the temperature difference between the board and the solder so that the solder temperature might be set higher than it need be to get wetting just to get faster heating to that melting point. The heating rate is also determined by the effectiveness of heat transfer across the interface so that another feature of vertical HASL machines designed for use with lead-free solder is faster circulation of the solder over the panel. The flow rate of solder across the board is already high in the horizontal process and because it is in-line a preheating stage can be easily included so that a lower solder temperature setting is possible.

Single-sided and simple double-sided boards can be HASL'd with a solder bath temperature of 260°C but to get the surface of a heavier multilayer board to wetting temperature in a reasonable time the solder bath temperature might have to be set as high as 280°C. However, the temperature actually reached by the laminate during its few seconds of exposure to this temperature is much less than that so that the integrity of the laminate is not compromised.

The temperature of the air impinging the surface of the panel as it emerges from the molten solder has to be above the melting point of the solder and the setting on a particular machine required to achieve that will depend on where the set temperature is measured. Typically a temperature setting similar to that for the solder bath is used.

Because it depends on the particular characteristics of the machine it is not possible to be specific about air knife settings such as air pressure, angle, proximity and offset but they differ from those that have often been used with tin-lead solder to the extent that the objective should be to leave enough solder on each pad to form the complete coverage exemplified in Figure 8. Because of the unevenness of the tin-lead finish the practice developed of blowing most of the solder off to leave a finish that is as flat as possible. With lead-free solder that can leave insufficient free (unreacted) solder to fully cover the intermetallic layer with a consequent negative effect on solderability, particularly after exposure to a solder paste reflow

Managing the Composition of the Solder Bath

As with the tin-lead HASL process the copper of the pads tends to dissolve in the solder so that the level of copper in the solder bath can quickly rise to more than 1%. As the copper content rises that liquidus temperature of the solder rises which means that there is a tendency for the needle-like crystals of Cu_6Sn_5 intermetallic to precipitate from the melt. These crystals have a higher density than lead-free solder and so tend to sink to the bottom of the solder pot from which they can be dredged. However, they also form in cold spots which are usually at the surface of the solder and so excess copper can often be removed by lifting these accumulations out of the bath. Since the rate of dissolution of copper decreases with the increasing copper content of the solder some operators let the copper levels rise as far as 1.2% and increase solder temperature to hold the copper in solution. The copper level of the solder bath can also be reduced by partially draining the pot and replenishing with a low-copper top-up alloy.

Coating Thickness

The profile of the solder coating in a HASL finish is determined by the volume of solder left on the pad after the board has passed through the hot air knife and surface tension forces. As illustrated in Figure 15, because of the way in which surface tension forces operate there is a tendency for the coating to be thicker on smaller pads.

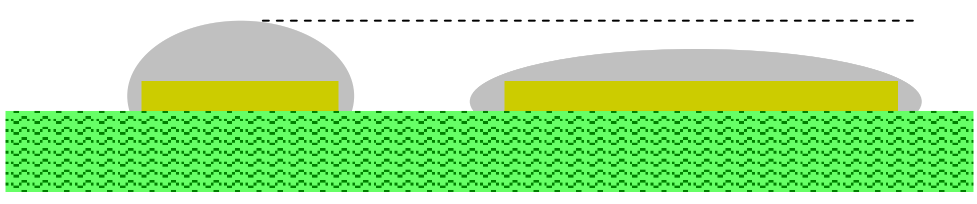


Figure 15. Surface tension forces mean coating tends to be thicker on smaller pads

Perhaps it is because of the higher surface tension of lead-free solder that the coating that it forms in the HASL process is both thinner and more uniform than that formed by tin-lead solder in similar circumstances[7]. (Figure 16)

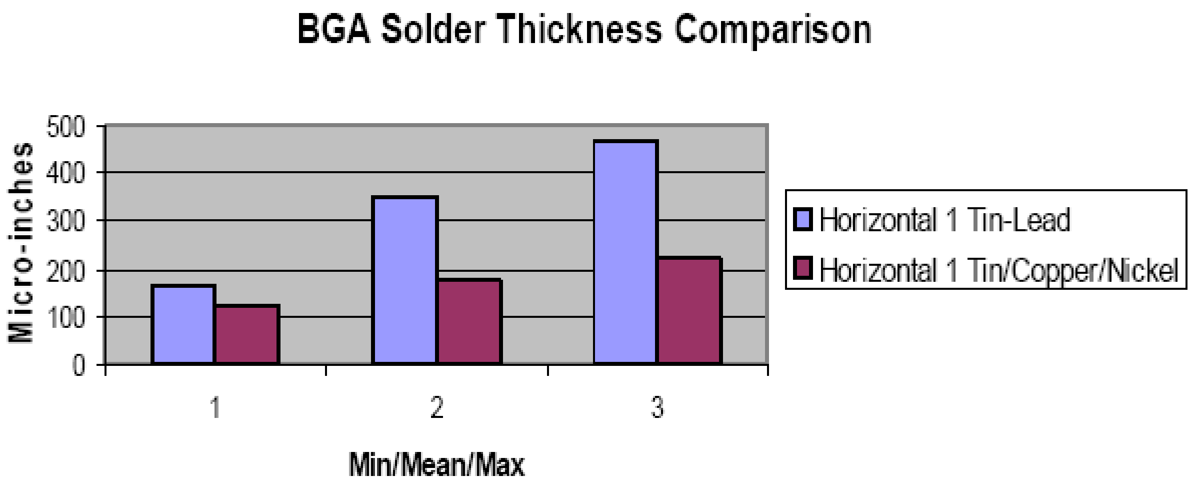
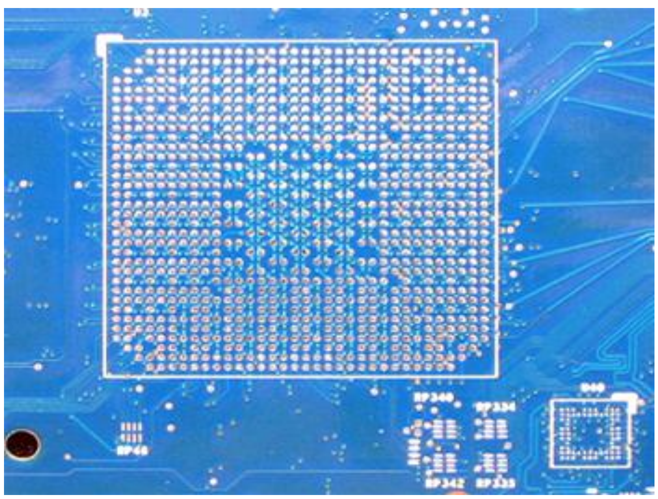


Figure 16. Comparison of HASL coating thickness (Fellman[7])

A typical range of thickness of an SnCuNiGe HASL finish on BGA pads (Figure 17(a) is given in Figure 17(b).



(a)

Pad size "	Pitch "	Mean coating thickness	Highest reading	Lowest reading	Number of readings
0.027 dia	0.05	4.93	7.19	2.45	78
0.018 dia	0.04	9.07	16.85	4.32	60
0.025 dia	0.05	7.45	10.51	5.49	75
0.020 dia	0.05	8.72	15.34	6.15	87
0.025x0.020	N/A	4.95	6.57	3.12	40
0.020 dia	0.05	4.8	9.83	2.53	104
0.030 dia	0.05	5.39	8.08	2.98	76
0.030 dia	0.05	5.04	6.91	2.61	140
Average		**6.29**	**10.16**	**3.71**	

(b)

Figure 17. Thickness of SnCuNiGe coating on BGA pads (courtesy Cemco/FSL Ltd)

Unfortunately the surface tension that contributes to a more uniform coating thickness also tends to pull the coating thin on the shoulder of plated through holes (Figure 18). However, if a sufficient volume of solder is left on the board a coating thickness of at least 1.5µm can be maintained and that is sufficient to ensure good through hole solderability even after several lead-free reflow cycles.

Whisker Susceptibility

Since the solder coating is applied in the molten form it is free of the residual compressive stress that is acknowledged as the primary driving force for whisker growth in electrodeposited coating. Testing to the JESD22A121 specification, "Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes" commissioned by the author's company has found that whiskers appear on a such a hot-dipped lead-free finish on copper only in areas where compressive stress was deliberately introduced and then only after 2000 hours under the most severe conditions provided in that specification- the combination of elevated temperature (60°C) and high humidity (87%RH). It was noted that for the silver-free SnCuNiGe alloy whisker growth ceased once the induced compressive stress had been relieved but in the SAC305 finish whisker growth continued, presumably driven by the stress generated by ongoing corrosion in the hot humid environment (Figure 19).

Trouble Shooting the Lead-free HASL Solderability

The lead-free HASL finish is intrinsically highly solderable so that if solderability problems are encountered during assembly the first step in diagnosis is to eliminate other possible causes of such problems, e.g. degradation of the activity of a solder paste. If the lead-free HASL finish is identified as the only possible cause the problem will be that complete solder coverage was not achieved on all areas to be soldered (Figure 20). This thin coating can be the cause of the dewetting apparent in Figure 9.

The Cost of Lead-free HASL

Although because their higher tin content and in some cases silver content lead-free solders are more expensive on a per kilogram basis than tin-lead solder other savings mean that lead-free HASL is not much more expensive than tin-lead HASL when all costs are taken into account[7]. The savings include the lower density of lead-free solders which provides an approximately 12% saving given that the important factor in a HASL finish is the volume of solder rather than its weight. And the thinner average thickness of the coating also results in a measurable reduction on the quantity of solder required per unit of area processed.

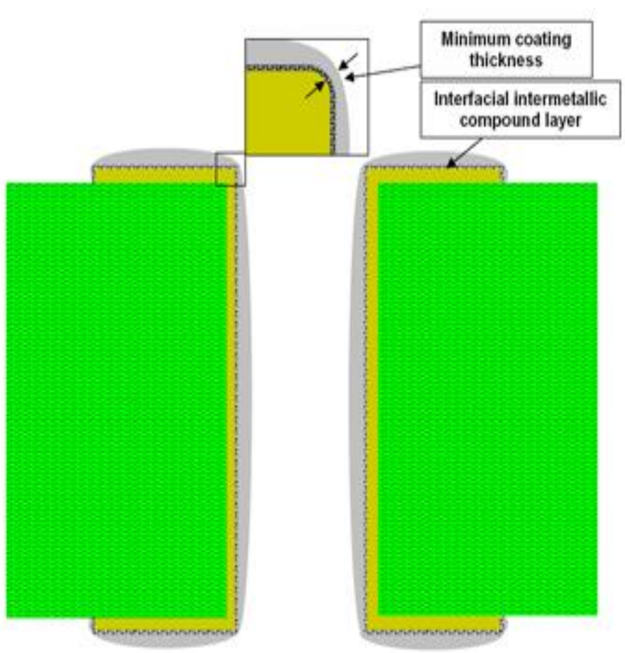


Figure 18. Minimum coating thickness on the shoulder of through holes.

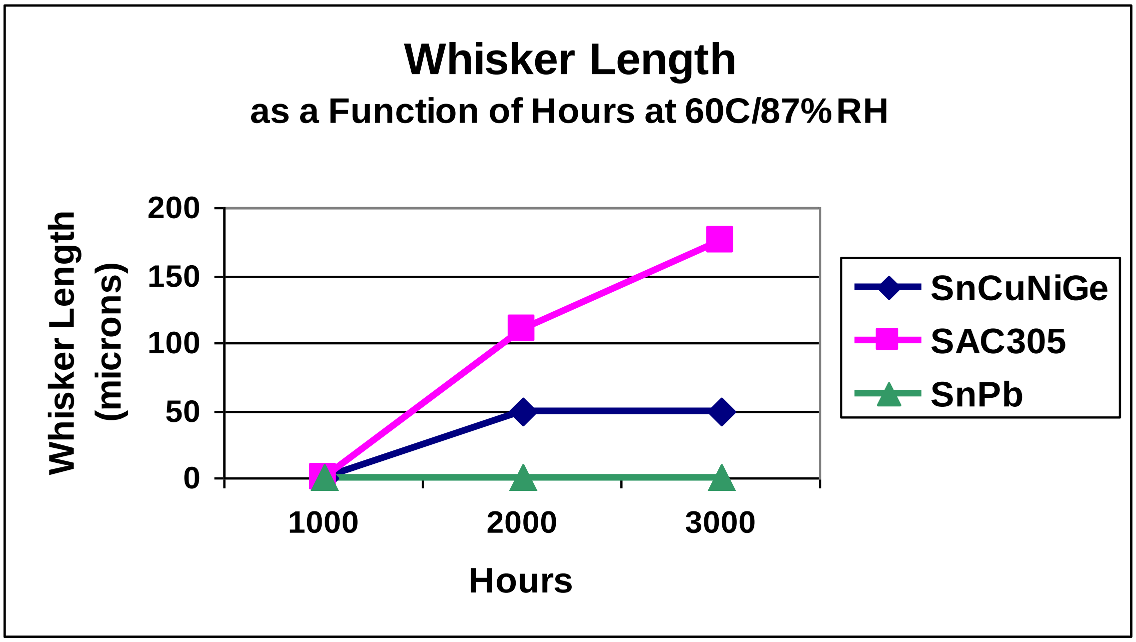


Figure 19. Whisker growth on hot dipped and stressed tin-lead and lead-free solder coatings on copper

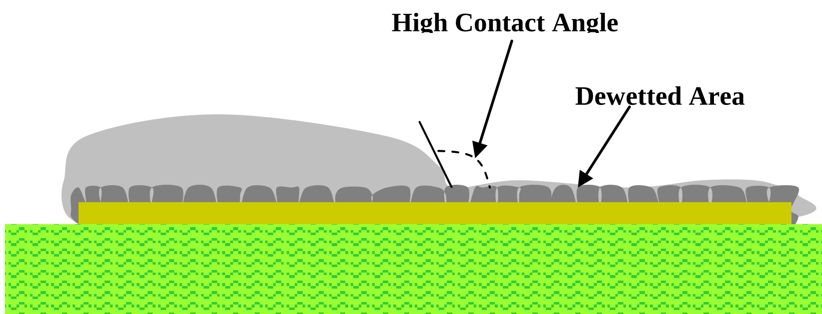


Figure 20. Dewetting of pad where there was insufficient thickness of solder over the intermetallic layer

Summary

- Lead-free HASL provides a printed circuit board with a corrosion resistant finish that can assure solderability over long periods of uncontrolled storage and through multiple lead-free reflow profiles.
- The lead-free HASL finish is superior to the tin-lead HASL finish in terms of uniformity of coating thickness.
- The main quality requirement for the achievement of the full potential of the lead-free HASL finish is a coating thickness that provides full coverage of the intermetallic layer that forms on a properly wetted copper surface.
- Best results in the HASL process are obtained with lead-free solders that come as close as possible to matching the eutectic behavior of tin-lead solder.
- A lead-free alloy formulated for minimum copper dissolution makes control of the solder bath composition easier and reduces the extent to which board reliability is compromised by reduced copper thickness.
- A lead-free alloy formulated for minimum growth of the intermetallic layer ensures maximum solderable shelf live and best final solderability in multi-stage soldering.
- While the vertical HASL process is still the most widely used the horizontal HASL process provides the most uniform finish and the high throughput required to meet the growing demand for this process.

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