Practical use of lead-free reflow soldering industrial method

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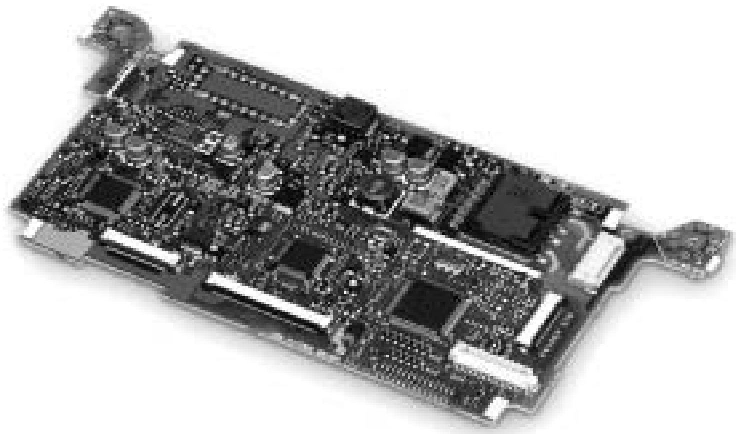

Abstract

Recent years have seen an increase in products using lead-free solder, especially those of domestic appliance manufacturers. Meanwhile automobile manufacturers have brought out specific guidelines for switching to lead-free solder, with an eye to European Union directives such as ELV and WEEE.

Thus the switch to lead-free solder looks set to speed up in various products.For in-vehicle equipment however, bringing the lead-free reflow method into practical use came up against the need to meet in-vehicle reliability requirements in terms of temperature, humidity thermal shock, etc. This has been a factor retarding the application of lead-free soldering to in-vehicle equipment.

For some time our company has been conducting technology development for practical use of lead-free solder,and last year we launched lead-free technology onto the commercial market in our navigation products, abreast of our rivals.

This paper presents the materials development, parts selection, reflow condition management and other aspects involved in bringing the lead-free reflow method into practical use.

1 Introduction

The problem of the harmfulness of the lead contained in solder has in recent years caused "lead-free solder" to be brought into practical use. This is solder that does not use lead, and its adoption by household electrical appliance manufacturers and others has made considerable progress. Furthermore, legal regulations on lead in electronic equipment have undergone strengthening as seen in the EU's Directives ELV[1] and WEEE/RoHS[2], so that there is an increasingly vigorous trend to eliminate lead from electronics materials.

Our company has kept pace with these developments by pursuing research for practical use of lead-free solder, and in 2002 we applied such technology to mass production for the first time in our commercialized navigation products (AVN), thus launching it on the market. Fig. 1 gives our schedule for achieving practical use of lead-free solder. Starting in this fiscal year we will gradually expand the range of our products that use lead-free solder, and all of our new products are scheduled to be lead-free from July 2005 onward.

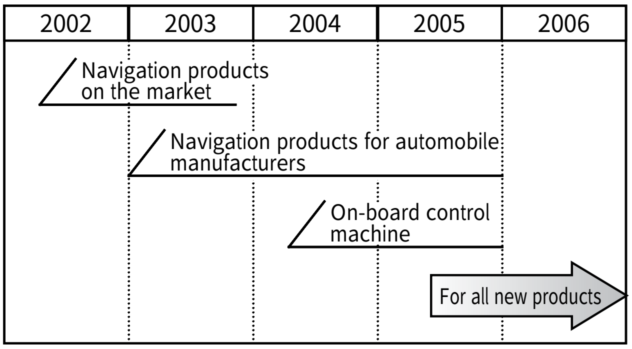

Fig.1 Schedule for practical use of lead-free solder

2 Lead regulatory trends

At present the only place in the world to have enacted legal regulations on lead is Europe. As mentioned above, such regulations take the form of the End of Life Vehicles (ELV) Directive, the Directive on Waste Electrical and Electronic Equipment (WEEE), and the Directive on Restriction of Hazardous Substances (RoHS) in electrical and electronic equipment. A description of these is omitted here since they were dealt with in issue No. 41 of this periodical, but simply put their effect is to ban the use of hazardous substances such as lead and mercury after July 1, 2006.

Whether they cover the lead contained in the soldering of circuit boards within waste in on-board electronic equipment is a gray zone that is still the subject of discussion. At any rate, non-use of lead is becoming unavoidable, and it is imperative to take urgent measures to tackle this issue.

Looking at the domestic trend in regulation, we see that although Japan has regulations concerning recycling and certain hazardous substances pursuant to the Electric Appliance Recycling Law (Specific Household Appliance Recycling Law) and Waste Disposal Law (Law on Waste Disposal and Public Cleaning), it still has no regulations imposing direct restrictions such as those mentioned above for Europe. However Japan Automobile Manufacturers Association, Inc (JAMA) has, as part of a voluntary initiative to reduce environment-burdening substances[3], set a target for the automotive industry with which our company is closely involved to cut use of lead to below 1 tenth of 1996 levels by 2006. Thus the elimination of lead from circuit boards looks set to speed up.

Against this background, automobile manufacturers have been adopting circuit boards using lead-free solder in some of their on-board equipment since around 2000, and will be steadily expanding the range of such equipment using such boards. These manufacturers have their eye on the EU's ELV and WEEE/RoHS Directives and JAMA's target year of 2006, by which time they plan to complete the transition to lead-free solder for all of their on-board equipment.

3 Problems with lead-free conversion

There are various methods of mounting parts onto circuit boards, including flow soldering and reflow soldering, and the total elimination of lead will necessitate developing technology to eliminate lead from each of these methods. Recently however the greater compactness and density of parts, coupled with multi-pin, small-pitch LSI packages, have resulted in boards with reflow soldering on both sides, such as that shown in Fig. 2, becoming the mainstream circuit board mounting configuration. This means that in order to proceed with the switch to lead-free boards, priority is being given to establishing technology to realize lead-free reflow soldering rather than lead-free flow soldering.

In bringing lead-free solder into practical use, it is desirable to retain as far as possible the currently used production equipment, conditions and design requirements, etc. But since the melt-point, wettability and physical properties of lead-free solder alloy differ from those of the conventional Sn-Pb solder, the conventional soldering methods cannot simply be adopted as they are. Furthermore it is also necessary to accommodate the fact that the parts density of the circuit boards used in on-board equipment has increased, and that such equipment is used under more severe ambient temperatures and humidities than household electrical products. Accordingly optimization has been carried out on the flux in the solder paste, the reflow conditions and reflow furnace conditions, the parts used, and the board design specifications, so as to make them suitable for lead-free solder.

The following and subsequent sections of the paper discuss such development work and the considerations behind it.

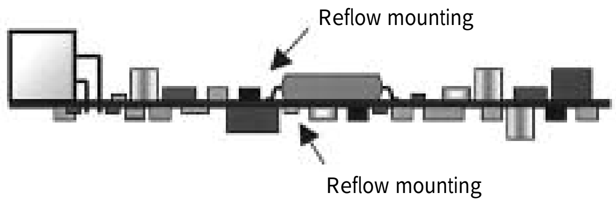

Fig.2 Process board with reflow soldering on both sides

4 Development of solder paste materials

4.1 Selection of the solder alloy

The lead-free solder alloy that was selected is Sn-3.0Ag-0.5Cu. This is in order to secure joint reliability, and for the reason that it has superior mechanical properties - tensile strength, elongation and Young's modulus - compared to other alloys. Table 1 lists the mechanical properties of various alloys.

The composition of this alloy is recommended by the Japan Electronics and Information Technology Industries Association (JEITA), and it is in widespread use in civil industry. Consequently this alloy offers supply stability and low cost, merits which, comparatively speaking, other alloys would be unable to provide.

4.2 Considerations for development of the solder paste

With solder paste for lead-free solder, it is necessary to compensate for the fall in wettability - which is one of the solder alloy characteristics - and to prevent oxidation of the Sn. Therefore such paste cannot contain the flux material that was used in the Sn-Pb solder paste hitherto. In particular there is the problem that when the reflow method is used with lead-free solder, there is a marked occurrence of the cavities known as voids in junctions after reflow, which results in a reduction in the joint and hence a fall in joint reliability.

The occurrence of these voids is held to be due to the following causes:

1) Lead-free solder has poor ability to wet electrodes.

2) The solder has high surface tension in the melted state, which renders vaporized flux unable to escape to the exterior.

Accordingly we conducted development of the flux for the solder paste with the goals of reducing occurrence of such voids while at the same time securing the insulation reliability under high-temperature high-humidity atmospheres and dew condensation that is so important for on-board product applications. Table 2 gives the composition of such flux.

Table 1 Properties of various lead-free alloys

Item	Lead-free solders				Current
	Sn-Ag	Sn-Ag-Cu	Sn-Cu	Sn-Zn	Sn-Pb
Melt point (℃)	221	216～220	227	199	183
Tensile strength (N/mm2)	41.0	53.3	30.9	45.5	56
Elongation (%)	58	46	45	40	56
Young's modulus (GPa)	43.2	41.6	32.8	53	25.8

Table 2 Flux composition table of lead-free solder paste

		Newly-developed product		Remarks
Content in flux		10.5%		
Resins	Rosin A (low softening point)	○	32%	Maintenance of moisture-proofing performance Synthetic resin and low softening point rosin resin are employed.
	Rosin B	○		
	Rosin C (high softening point)	—		
	Synthetic resin	○	24%	
Activators	Halide	—	4%	Securing of wettability and continuous printing performance Non-ionic activators are adopted and halide materials are discontinued.
	Organic acid based	○		
	Non-ionic	○		
Solvents	Low boiling point	○	33%	Securing of low void rate and continuous printing performance Blended solvent is adopted.
	High boiling point	○		
Thixo materials/additives		○	bal	

4.2.1 Means to improve the wettability

Alongside the switch to lead-free solder material, a switch to lead-free material for plating of part electrodes is also underway, with the conventional solder plating being progressively replaced by Sn, Sn-Bi and similar. But since such plating materials have higher melt points and are more prone to oxidation compared to the conventional solder plating, they result in lower wettability of the electrodes.

We dealt with this problem by selecting as the activator used in the solder paste a material that is able to assure good wetting on the plating, especially Sn plating.

Fig. 3 presents the results of an investigation of wetting times when the newly-developed activator is used and when an ordinary activator is used.

It can be seen from these results that the newly-developed activator for lead-free solder provides good wetting, without the paste being affected by the plating material.

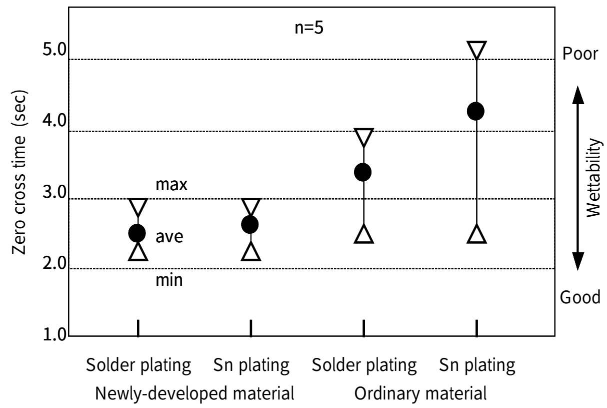

Fig.3 Relationship of wetting time and activator

4.2.2 Means to curb generation of flux vapor during reflow

The main component that is vaporized during reflow is the solvent contained in the flux. Hence, in order to curb vapor generation during reflow, it is desirable to raise the volatility of such solvent, by lowering its boiling point, so that none of the solvent will remain by the time that reflow heating is performed. However, lowering the boiling point excessively will result in high volatility even at normal temperature, and such high solvent volatility will raise the viscosity of the solder paste, so that continuous print performance over prolonged periods becomes impossible to secure. As a means of resolving such conflict of characteristics, and achieving a balance between boiling point and volatility, we implemented volatility adjustment of the solvent component.

There were two target values to be attained by such adjustment:

1) **Percentage of voids beneath chip electrode:10% or less - to secure joint reliability.**
2) **Period over which continuous printing is possible: 8 hours or more - to secure productivity.**

Fig. 4 shows the temperature versus volatility characteristics of the adjusted solvent.

Various experiments conducted to date have demonstrated that in order to achieve the targets, the volatility characteristics will have to be such that:

1) **a volume of 0.2% or less by weight evaporates from normal temperature up to 55°C, and**
2) **a volume of 20.0% or more by weight evaporates from normal temperature up to 170°C.**

The adjusted solvent satisfies these volatility characteristic requirements, and thus makes it possible to achieve both the requisite continuous printing performance and a low void percentage.

The various characteristics of the solder paste material developed in the above manner are given in the following section.

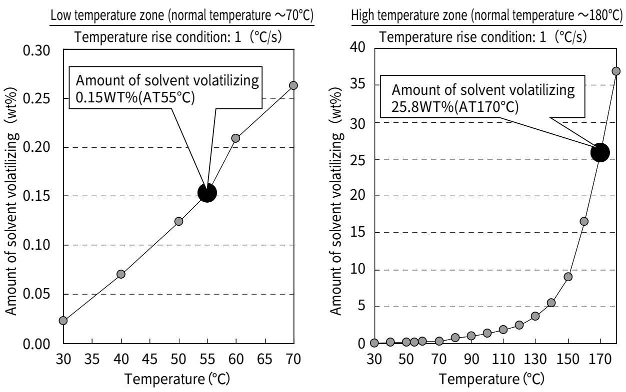

Fig.4 Volatility characteristics of newly-developed solvent

4.3 Basic characteristics of the solder paste

4.3.1 Soldering quality

In order to assess the solderability of the newly-developed lead-free solder paste we investigated the occurrence of tombstones and solder balls during reflow of chip parts (sizes 1608, 3216 and 6432), using actual products. The results are shown in Fig. 5.

Just as with the current Sn-Pb solder, no tombstones occurred when there was no paste printing gap or part mounting gap. When such gap was present however, tombstones did occur with the lead-free solder. This would indicate that the lead-free solder offers no leeway as regards non-uniformity of mounting condition during the manufacturing process. Countermeasures for such difficulty will be described in 5.2 below. In devising such countermeasures we concurrently determined the occurrence of solder balls, which was low compared to the current solder. The countermeasures are aimed to further reduce solder balls at the same time as reducing tombstones.

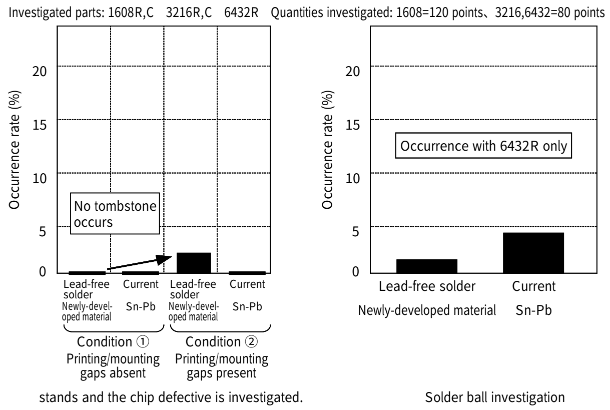

Fig.5 Soldering quality of lead-free solder paste

4.3.2 Continuous printing performance

Solder paste is fed via screen printing. That means that in continuous printing it is important that the solder is fed stably.

Here we present the results of a comparison of the newly-developed lead-free solder paste's performance with that of an ordinary commercially available item, which was conducted by determining the transfer rate in continuous printing lasting 8 hours with a 0.4mm pitch QFP pattern.

The transfer rate was calculated using the following formula:

Transfer rate (%) = printed area / mask opening area

The results of the evaluations are given in Fig. 6.

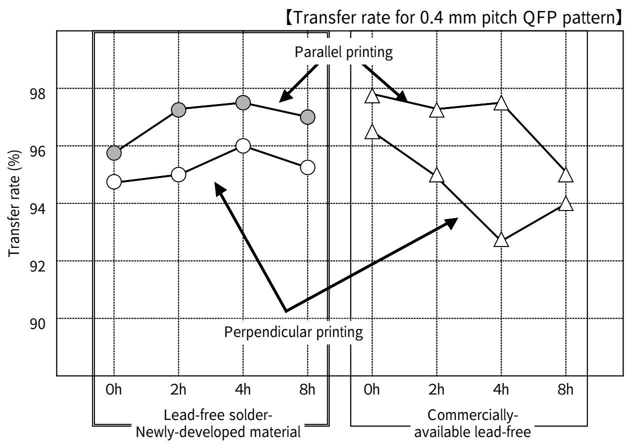

Fig.6 Performance of continuous printing

As will be seen, the newly-developed paste can provide extremely stable printing that changes very little with time, even up to periods of 8 hours and beyond. This is because its solvent component has been optimized in the manner described earlier.

4.3.3 Results of reliability evaluation

The newly-developed lead-free solder paste inherits unchanged the moisture-proofing function that our company brought into practical use some time ago for Sn-Pb solder paste[4]. The moisture-proofing function refers to flux residue covering over the soldered portions after soldering, thereby protecting them from humidity or condensation. It is a technique that has been adopted as a coating substitute since 1996.

The reliability required of the moisture-proofing function is evaluated using the following 3 parameters:

①Thermal shock test:
Deterioration or cracks in the residue film resulting from the thermal stress..

②Low-temperature recovery test:
Degree of drop in the inter-pattern resistance values due to frosting (condensation) occurring during low temperature R normal temperature.

③Insulation resistance test:
Reliability of inter-pattern insulation under conditions of high temperature and high humidity.

Below we give accounts of the results of each of these tests.

①Results of thermal shock test

Because its linear expansion coefficient differs from that of the circuit board, the film of flux residue film that is formed on the board may develop cracks as a result of the stress occurring under thermal shock. If moisture enters the cracked portions, leak faults and similar problems will result.

We investigated cracks in the flux residue film that occurred in a thermal shock test using -30/80°C, the normal test conditions for on-board equipment. Fig. 7 shows the appearance of the lands after such test.

With the commercially-available product, cracks are observed in the flux pile-up portions at the land periphery after the test, but no such cracks are observed with the newly-developed product, in which the film is preserved in good condition.

②Results of low-temperature test)

This test evaluates the degree of the drop in the inter-pattern insulation resistance caused by the condensation that forms on the circuit board's surface when the board is brought back from a low temperature to normal temperature.

Specifically, in this test the circuit board is left in a -30°C atmosphere for 24 hours, then is taken out into the normal-temperature atmosphere, whereupon the change in the resistance value is measured. The test samples undergo the thermal shock test as preparatory treatment, so that deterioration of the flux residue film can be included in the consideration.

The results were as shown in Fig. 8a. Whereas the resistance drop due to residue film cracks was large with the ordinary commercially-available material, with the newly-developed product the resistance showed a level that was 1 order higher compared to the commercially-available products.

③Results of insulation resistance test

This test evaluates insulation resistance level in a high-temperature, high-humidity atmosphere.

The test conditions were: voltage of 16V applied continuously for 1000 hours in an 85°C, 85% RH atmosphere.

The results were as shown in Fig. 8b. Just as in the low temperature recovery test, the newly-developed product's resistance value showed a level that was 1 order higher than those of the commercially-available products.

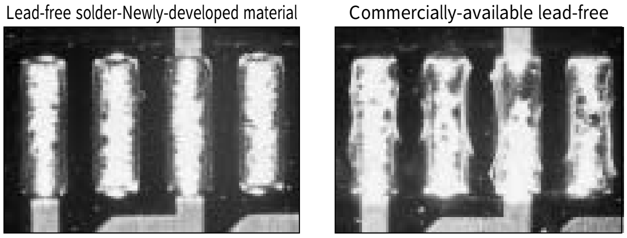

Fig.7 Thermal shock resistances of flux residues

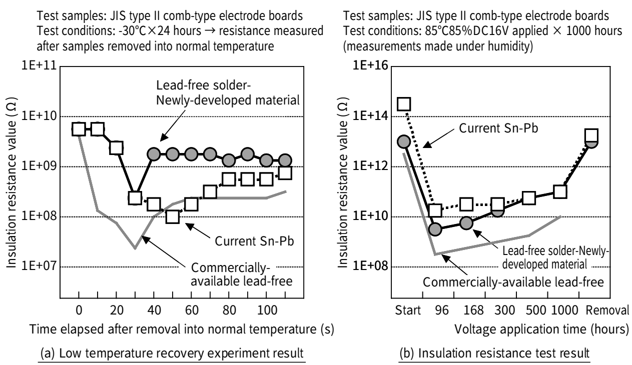

Fig.8 Reliability of flux material

As is clear from the foregoing, the flux material of the newly-developed lead-free solder paste assures insulation reliability and moisture-proofing performance that are comparable to those of the currently adopted Sn-Pb material.

5 Soldering methods

5.1 Reflow profile

5.1.1 Minimum melting temperature

The melt point of the new lead-free solder alloy that we selected is some 40°C higher than that of the current Sn-Pb solder alloy, so when the new solder alloy is used the soldering temperature must be raised to match the

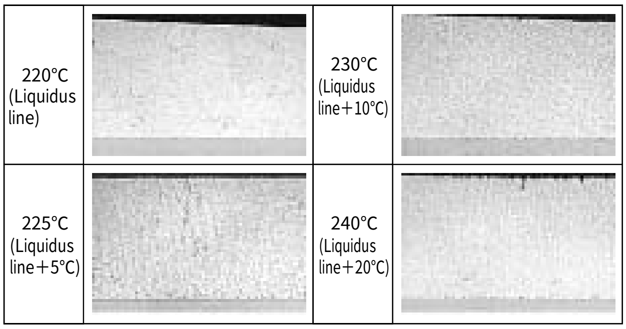

Fig.9 Images of structures at various melt temperatures

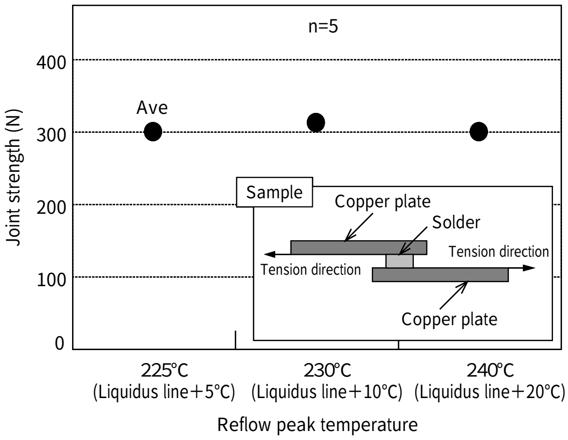

Fig.10 Joint strength at various melt temperatures

rise in the melt point. The bottom limit soldering temperature for the Sn-Pb solder is its liquidus line temperature +about 20°C, but under identical conditions the bottom limit soldering temperature for the lead-free solder will be around 240°C, which could render soldering impossible depending on the heat resistance temperature of the parts concerned. Accordingly, we examined the cross-sectional structures of the solders, and the strength of joints made with them, when various soldering temperatures are used, so as to determine what are the actual bottom limit temperatures at which the solders melt (their minimum melting temperatures). Fig. 9 shows the cross-sectional structures, and Fig. 10 the joint strengths, with various temperatures.

Looking at the cross-sectional structures, it was found that in the vicinity of the liquid phase line at 220°C the structure was coarse, with the solder poorly melted. Further, it was determined that the joint strengths are comparable between 225 and 240°C, the minimum melting temperature being 225°C. Taking account of the accuracy of reproducing such temperature level in actual equipment, we set the bottom limit temperature for reflow soldering at 230°C.

5.1.2 Selection of the reflow furnace

When printed circuit boards are reflow soldered, non-uniformity occurs in the reflow peak temperature because of differences in the heat capacity of each mounted part. If the temperature profile of the currently-used reflow furnace were changed to accommodate the newly-set soldering bottom limit temperature, in an attempt to make the furnace suitable for lead-free solder, the peak temperature at certain points on the circuit board's surface could rise and exceed the parts' heat resistance.

Accordingly we brought in a new reflow furnace that is divided into multiple zones and has enhanced hot air heating efficiency, features giving it high heat focusing ability that can even out the temperatures on the board's surface. Such furnace reduces non-uniformity in the board surface temperatures to a low level, thus safeguarding the part heat resistances.

5.1.3 Management of reflow profile

As mentioned above, non-uniformity occurs in the preheat curve and peak temperature in reflow soldering, due to the effects of the sizes of the parts that are mounted, and the mounting density. To deal with this we set a control margin that will yield peak temperatures that can assure the part heat resistances and minimum melting temperature, along with preheat temperatures that match such peak temperatures, as shown in Fig. 11.

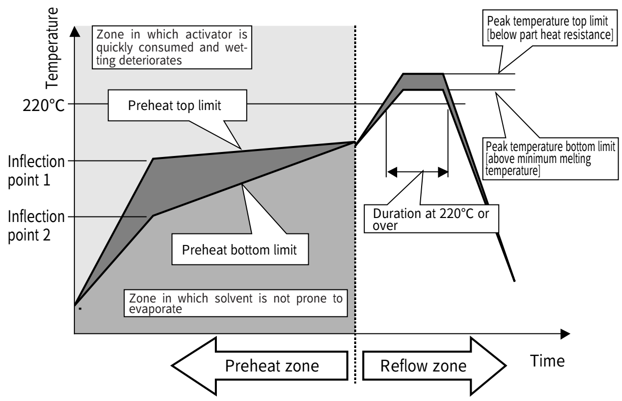

Fig.11 Management of reflow profile

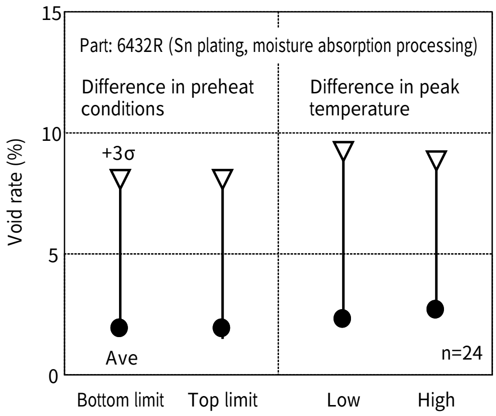

Fig.12 Effect of reflow profile on voids

On the basis of such control margin we investigated the occurrence of the voids that are prone to occur beneath the chip electrodes and are a major factor in soldering quality, having a large impact on joint reliability. Fig. 12 shows the results of such investigation. It determined that within the newly-devised control margin, the preheat-curve and peak temperature have little effect on the occurrence of such voids.

5.2 Countermeasures for chip tombstones

5.2.1 Design of lands and metal masks

As mentioned in 4.3.1 Soldering quality, it was found that lead-free solder affords no leeway for printing and mounting gaps as regards tombstones.

In order to curb tombstones, it is necessary to prevent reduction in the area of contact between the electrodes and the solder that is caused by printing and mounting gaps - in other words to prevent a fall in the tacking force. Accordingly we adjusted the land interval and the metal mask opening interval so as to secure an ample area of contact between the electrodes and solder when gaps occur, and in this way we were able to curb tombstones. Fig. 13 gives the results of evaluation of this method's efficacy when gaps were induced in actual products.

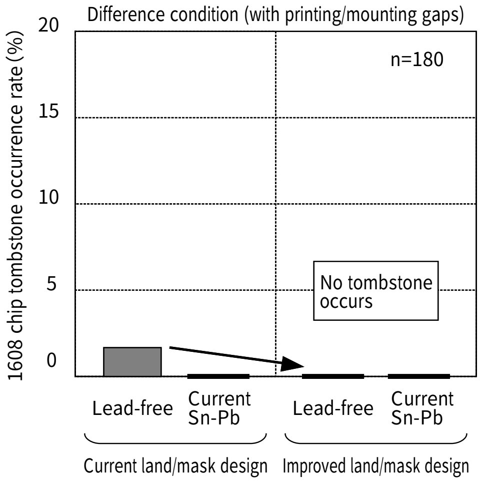

Fig.13 Improvement of tombstone via land design

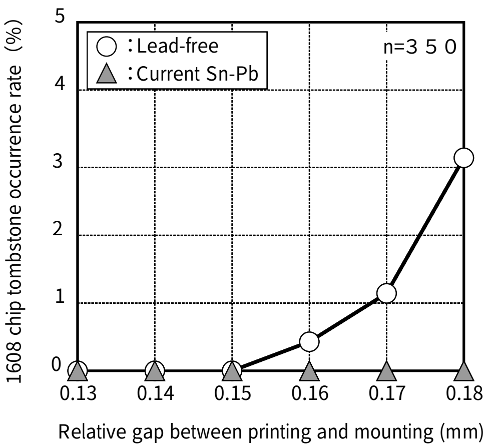

Fig.14 Effects of print gap and mounting gap on tombstone

5.2.2 Printing and mounting equipment

Next we investigated to what degree printing gap and mounting gaps exert effects when the land and metal mask design values determined as described in the previous section are adopted. The results of such investigation are shown in Fig. 14. It was found that with the lead-free solder the degree of leeway with regard to gaps is far smaller than with the Sn-Pb solder, so that in order to curb tombstones the relative gap between paste printing and part mounting must be kept below 0.15mm. This means that high-accuracy printing equipment and parts mounting equipment will need to be used in order to secure soldering quality with the lead-free solder.

6 Product selection

6.1 Part electrode plating

A switch to lead-free plating for the part electrodes is being implemented alongside the switch to solder-free lead. Hitherto the great majority of such plating has been Sn-Pb based, but with the switch to lead-free plating a variety of other plating materials such as Sn-, An-Bi- and Au/Pd-based are making their appearance. We conducted investigations on such new platings as regards the condition of joints following soldering and the reliability of joints under the thermal shock test. The results are compiled in Table 3, which gives a list of the compatibility of such platings in combination with the lead-free solder.

The following parts platings were found to be incompatible with the lead-free solder: Sn-Bi(Bi>2% by weight), Au/Pb/Ni(Pd>0.1 micron), and Sn-Pb. The incompatibility of Sn-Pb plating and of Sn-Bi plating with Bi content exceeding 2% by weight is due to the fact that when flow

Table 3 Compatibility of lead-free solder with part plating

Solder material		Lead-free solders			Current Sn-Pb Solder		
Part configuration		SMD		THD	SMD		THD
Soldering method		Reflow	Flow	Flow	Reflow	Flow	Flow
Part plating	Sn	○	○	○	○	○	○
	Sn/Ni	○	○	○	○	○	○
	Sn-Ag	○	○	○	○	○	○
	Au	○	○	○	○	○	○
	Sn-Cu	○	○	○	○	○	○
	Sn-Ag-Cu	○	○	○	○	○	○
	Sn-Bi(Bi≦2.0wt%)	○	○	○	○	○	○
	Sn-Bi(Bi>2.0wt%)	○	×	×	×	×	×
	Au/Pd/Ni(Pd≦0.1μm)	○	○	○	○	○	○
	Au/Pd/Ni(Pd>0.1μm)	×	×	×	×	×	×
	Sn-Pb	△	×	×	○	○	○

○ : Compatible × : Incompatible △ : Compatible if care is used

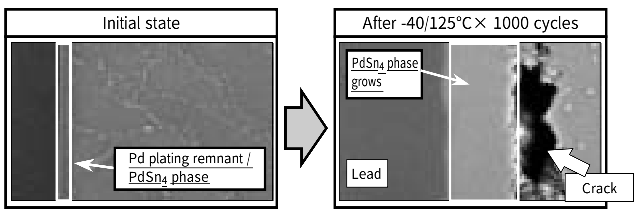

Fig.15 Reliability decrease due to plating residue (Au/Pd/Ni Plating)

soldering is performed on them, lift-off occurs and furthermore their Bi or Pb contaminates the solder in the flow solder bath. For Au/Pd/Ni, the incompatibility is as follows (refer to Fig. 15): if the Pd plating is more than 0.1 micron thick, Pd remains on the joint interface after soldering, and the effects of thermal shock as in the thermal shock test cause such plating remnant to grow into a thick PdSn4 phase, which will cause cracks and thereby lower reliability[5].

In addition, when soldering Sn-Pb plating parts with a reflow process using lead-free solder, a low melt point alloy of Sn-Ag-Pb is formed in the solder fillet, near the surface of contact between the solder and the lead line. If heat is then added through a later process such as flow soldering, the low melt point may give rise to peeling.

Therefore, careful attention is required when using Sn-Pb plating.

6.2 Heat resistance of parts

In line with the higher melt point of the lead-free solder, a new reflow furnace was introduced and changes were made to the reflow profile, as described in 5.1 above. In spite of these measures however, a rise in the reflow peak temperature is unavoidable. As a result, in some cases it is not possible for the parts heat resistance specifications used with the current Sn-Pb solder to assure heat resistance of parts under the new lead-free reflow soldering conditions.

Accordingly, we amended our part heat resistance specifications to take account of the lead-free reflow temperature conditions, and requested the parts manufacturers to raise the heat resistance levels of their parts. Not all of the parts meet the amended heat resistance specifications as yet, but the range of parts accommodating the new specifications is steadily expanding thanks to the efforts of the manufacturers.

In some cases the requirements have been met through a switch to high heat resistance parts such as aluminum electrolytic capacitors, which has resulted in higher part costs.

6.3 Soldering reliability with various part sizes

Lead-free solder has traditionally been held to have high soldering reliability due to the fact that the mechanical strength of the alloy itself is higher than that of Sn-Pb solder.

However, reliability tests using a variety of parts revealed discrepancies in reliability as between lead-free solder and the current Sn-Pb solder, as can be seen from Fig. 16. With small chips such as size 1608 the lead-free solder and the current Sn-Pb solder have comparable reliability. But large chip resistors tend to result in an accelerating increase in the crack percentage after 1000 cycles, and consequent fall in reliability, such tendency being even stronger with the lead-free solder than with the Sn-Pb solder.

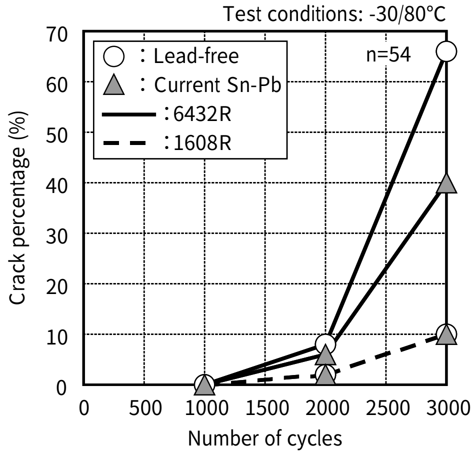

Fig.16 Part size versus percentage of clacks

This is presumably because the current SN-Pb solder creeps extremely readily, which alleviates distortions caused by thermal shocks, whereas the lead-free solder with its high proportion of Sn and its zero lead content exhibits very little creep shape-change, so that residual stress builds up in it without being alleviated, resulting in a steep increase in the crack percentage.

In the interest of rendering the lead-free solder practically usable therefore, we compiled a chart representing part size versus soldering reliability, and used it to formulate lead-free design standards that prohibit the adoption of parts that cannot meet the requirements for on-board reliability.

Design work that is currently being carried out for products under development reflects the guiding principles embodied in such standards.

7 Deployment to mass production

As mentioned at the beginning, our company began its program for practical use of lead-free solder in 2002, and in the present year we have been expanding the range of equipment items to which lead-free solder is applied.

In the present section we take as an example a display circuit board for use in navigation, which began being produced in April of this year, and discuss the circumstances of its mass production.

The parts that are mounted onto this display circuit board include 0.5mm pitch QFPs, surface-mounted multiple-pin (60-pin) connectors, and size 1005 chip resistors - in fact, nearly all of the circuit board elements that are commonly produced at the present time. Thus it is suitable for verifying soldering quality with fine-pitch parts, microparts and the like.

To describe briefly the soldering quality of this circuit board: although non-wetting and bridges occur with it, it suffers from none of the tombstone troubles that were a cause of concern as described in 5.2 above. Further, the cause of the non-wetting is poor wettability of certain parts. Hence the major problems are rather with the state of the part electrode plating than to do with the solder paste or reflow conditions. Accordingly, the parts manufacturers have been requested to make appropriate improvements.

Bridges occur in these circuit boards at a comparable rate to comparable boards using the Sn-Pb solder. The causes of the bridges are considered to be paste printing gaps, mounting gaps, misalignment of part terminals and similar. Improvements to ameliorate this problem are underway on a general basis (not only for products using lead-free solder).

We additionally investigated deterioration of the solder paste when it is used in continuous printing. Fig. 4 presents the results. Generally when solder paste is used continuously, the solvent component in the paste is likely to evaporate, causing a rise in the paste's viscosity and hence a fall in printability and deteriorated solderability. However, no deterioration of the printability, tackability, soldering quality or other characteristics of the newly-developed solder paste was found to occur when it was used continuously, although its viscosity did rise a little. This is thanks to optimization of the resin and solvent components in the new paste's flux.

From the foregoing results it will be appreciated that reflow soldering using lead-free solder has reached a level that amply permits its practical application. From now on we intend to expand the range of products to which the new soldering is applied.

Table 4 Results of investigation of solder paste deterioration

Items	Sample	Value	Solder paste lot			
			1st	2nd	3rd	4th
Viscosity	<220 (Pa.s)	Initial	161	157	161	157
		After use	193	209	180	196
Wetting time	<0.8 (sec)	Initial	0.53	0.56	0.53	0.56
		After use	0.54	0.53	0.56	0.54
Tacking force	1.0< (N)	Initial	1.66	1.53	1.66	1.53
		After use	1.65	1.54	1.55	1.56
Solder ball test	C2 (level)	Initial	C2	C2	C2	C2
		After use	C2	C2	C2	C2
Judgment			○	○	○	○

Solder ball test：C1 (excellent) ⇔ C5 (poor)

8 Other than reflow methods

Thus far our discussion has concerned reflow soldering. But in order to realize the switch to lead-free soldering for all printed circuit boards, lead will have to be eliminated in other forms of soldering besides the reflow method. It will also be necessary to give attention to repair (correction) following soldering. Accordingly, below we briefly discuss the flow method, manual soldering, and repair processes.

8.1 Flow method

Even now the flow method remains one of the most important soldering methods in the production of printed circuit boards. In order to carry out flow soldering using lead-free solder it is necessary, just as for reflow soldering, to optimize the soldering temperature and duration in line with the higher melt point of the solder, to make improvements to the flux so as to enhance wettability, and to optimize the shape of the circuit board's lands. Additionally, measures must be taken to counter the problem of eating away of copper foil caused by the solder corroding and rendering thinner the board's copper foil and through holes, as well as the problem of voids.

Our company is currently moving ahead with development of such technology, and plans to proceed in due course to mass production of circuit boards adopting a lead-free flow soldering method, en route to achieving lead-free soldering for all of its products.

8.2 Manual soldering and repair processes

In reflow and flow soldering, the thermal stress on the circuit board and parts can be made more or less constant via setting of the equipment conditions. But with manual soldering, differences in the heat capacities of the parts to be soldered and the work methods mean that the volume of heat delivered by the soldering iron will not be constant, and this fact must be taken into account as concerns the heat resistances of the boards and parts involved.

During manual repair of faults occurring in reflow or flow soldering, heat is liable to be applied repeatedly to the affected areas. This requires careful prior deliberation, so that the intended repair does not mistakenly result in breaking of the board's through-hole connections or in spoiling of parts.

Another problem that is liable to occur with soldering repairs is use of the wrong solder material. Specifically this refers to the use of the current Sn-Pb solder to repair boards soldered with the lead-free solder, or vice-versa. Table 5 gives the results of an investigation of the com-

Table 5 Compatibility when soldering is performed with differing alloys

Wire solder material / Initial solder material	Current Sn-Pb solder	Lead-free solder
Current Sn-Pb solder	○	×(※1)
Lead-free solder	×(※2)	○

※1 Occurrence of lift-off　　※2 Incomplete melting and mingling

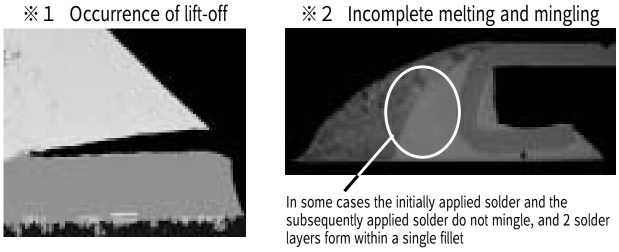

Fig.17 Examples of troubles when soldering is performed with differing alloys

patibility of initially used solder materials with wire solder materials used for repair. In each case, faults were found to occur when the repair material was different from the initial material.

Fig. 17 provides cross-sectional photographs of such faults.

As can be seen, using different solders in this way results in problems in the joint that will lead to a fall in reliability, such as occurrence of lift-off and inadequate mingling of the solder added for repair with the initial solder. Hence, until the solders currently used in our manufacturing processes are all replaced with lead-free solder, it will be necessary to manage the processes stringently so that such mixing of solder materials does not occur.

9 Conclusion

Above we have described some of the key points in the efforts being undertaken toward bringing lead-free solder into practical use, focusing mainly on "reflow soldering". Although mass production using lead-free soldering began last year, there are still many difficulties to be resolved before all of our printed circuit boards can be made lead-free. And further heightening of technology levels will be required in order to assure the reliability over prolonged periods that is needed for on-board environments with their severe temperature, humidity and vibration conditions.

We will be continuing our technology development so as to complete the switch to lead-free soldering in new products by July 2005 that was mentioned at the start of this paper. By so doing we will be providing environment-friendly products.

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