Development of lead free vehicle products

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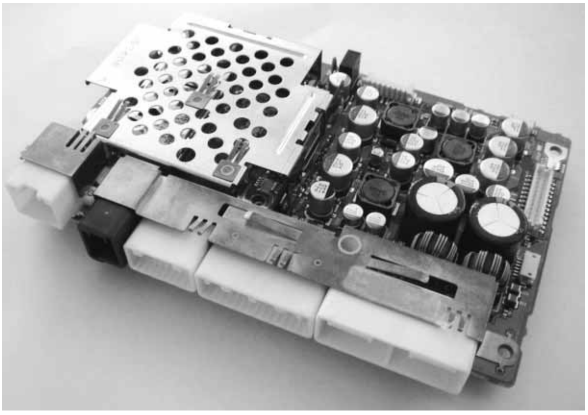


Abstract

From the issue of the WEEE/RoHS directive for earth environmental protection, there has been an increase of products using lead-free solder centered on household electronics manufacturers. There is a transition towards lead-free solder in -vehicle products as well, following the issue of the European ELV directive.

With the reflow soldering process, lead-free solder had been proceeding toward practical use in navigation products for auto manufactures since 2003, and lead-free solder in vehicle-control products were adopted in 2004. Now that we have succeeded in introducing completely lead-free products into the market including their flow process.

In order to ensure reliability of in-vehicle products, the establishment of soldering process that corresponds for lead-free, component selection, evaluation/conversion, and design requirements are needed. Therefore, this document introduces the working system and problem solving solution in these respects.

1 Introduction

In recent years, directives such as WEEE/RoHS[1] and European ELV[2] are requiring provision of Earth environment friendly products. Figure 1 shows regulations regarding environmental protection. Fujitsu Ten has been working in various environmental compatibility issues ourselves, and one major issue is the change to lead-free automotive products.

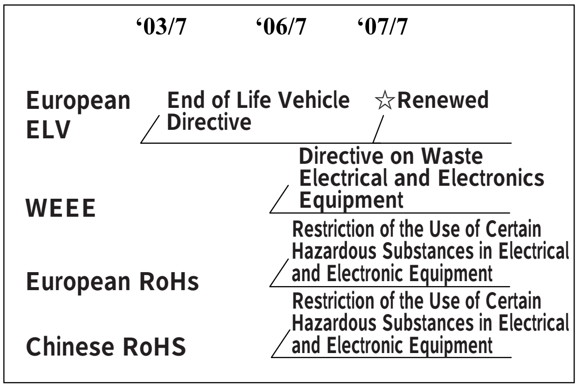


Fig.1 Various regulations regarding environmental protection

Figure 2 shows the lead-free product plan at Fujitsu Ten. Double-sided reflow processes are becoming the mainstream for component mounting at Fujitsu Ten, and we have been starting the introduction of reflow processes using lead-free solder into the market, starting from navigation products in 2003. From 2004, we performed lead-free reflow mounting for vehicle control products, and in 2005, we were able to introduce a reflow and flow soldered navigation product with completely lead-free solder.

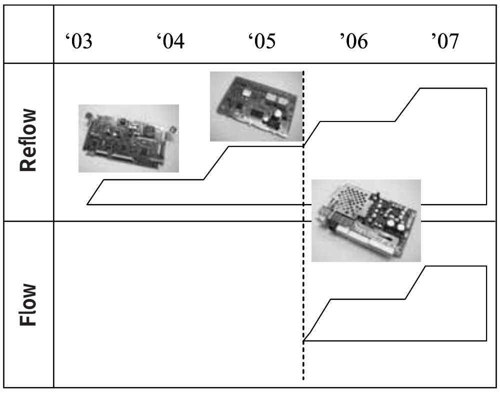


Fig.2 Schedule for practical use of lead-free solder

2 Issues in conversion to lead-free solder

Lead-free solder (Sn-Ag-Cu) differs from the conventional Sn-Pb solder in alloy melting points, wettability and other physical properties, and it is not possible to use conventional soldering processes[3]. In comparison to household electrical products, vehicle mounted products are faced with harsh environmental requirements involving severe ambient temperatures and humidity, and they also require high density mounting onto their circuit boards. In order to create lead-free products, it is necessary to establish a soldering process and selection of parts that accommodates for lead-free solder, perform evaluation and changeover, and establish design parameters.

Figure 3 shows technical evaluation issues for mass-production of lead-free products, and the following chapter describes organization and measures for these issues.

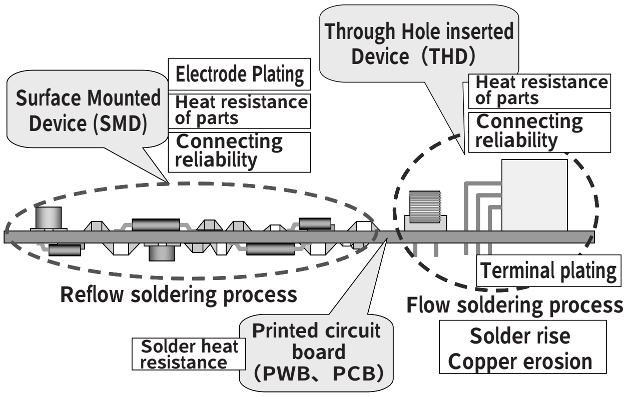


Fig.3 Technical evaluation issues for mass-producing lead-free products

3 Work organization

There are two aspects to making a product lead-free. The part electrode plating must be made lead-free, and the soldering material must also be made lead-freeA massive quantity of parts electrode plating must be made lead-free during the transition period, and it is necessary to evaluate each part smoothly without fail. For this purpose, a new "Common parts project section" (hereafter, abbreviated as common parts pro.) was established as a company wide organization, for centralized management and guidance of part changeover throughout purchasing, manufacturing engineering, production and design departments.

As shown in Figure 4, the Common parts pro. was newly established in the lead-free promotion project organization.

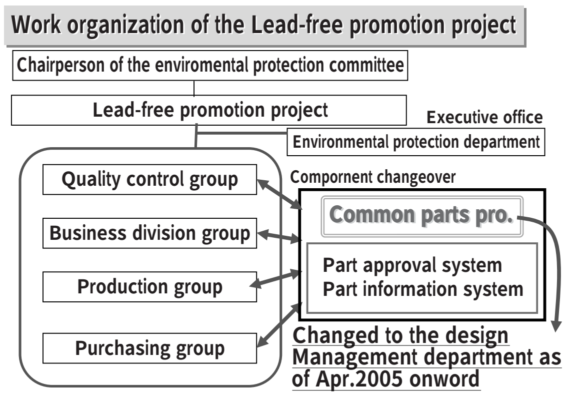


Fig.4 Project organization for lead-free component transition

In regards to the centralization of part information, the part approval system (performing approval for usage according to evaluation result of design, mounting and supplier instruction, etc.) was changed to allow registration of whether a part is lead-free compatible or not, and the design investigation was performed in Common parts pro. Target parts were parts currently in use, and parts that were planned for usage, and whether they are lead-free compatible or not was determined based on new approval standards. Because there will be a change in part electrode plating, the approval standards were reviewed by the material development department and manufacturing engineering department, for wettability and heat resistance of part. A new selection guideline was established by the design department, using the evaluation analysis results of solder connecting reliability. The changeover to approved parts were made while making adjustments with the design department, and we were able to complete the changeover by the end of 2004.

For the change in components, there was an effect to joint quality when the solder material was changed, so we proceeded first with making part electrode plating lead-free.

Table 1 Compatibility problem with component terminal plating

			Part electrode plating	
		Process	Sn-Pb	Lead-free
Solder materials	Sn-Pb	Reflow	○	○
		Flow	○	○
	Lead-free	Reflow	× →	○
		Flow	× →	○

The evaluation results and the status of the change in parts can be viewed by searching part information in the company system. An example of a search on the part information system is shown in Figure 5.

This made it possible to check the lead-free compatibility status per part number, and the engineers were able to reflect this into the product design.

Through this activity for the change to lead-free products, overlapping parts were consolidated and part drawing quality was greatly improved at the same time.

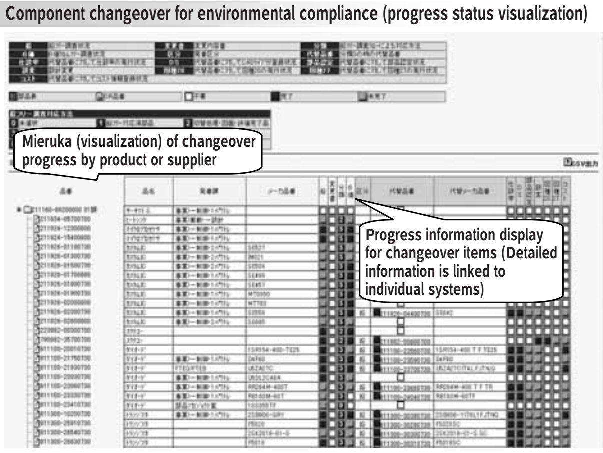


Fig.5 Search example of the component information system

In the same manner as standard parts, printed circuit boards are versatile and they have a large effect to product reliability, requiring evaluation and management in related departments. Circuit board approval work was therefore integrated as a role of Common parts pro. to consolidate work and optimize.

The Common parts pro. was disbanded at the end of March 2005, but this type of part management and circuit board approval is continued in the design management group.

Next we will explain how solutions were found for technical issues through this work organization.

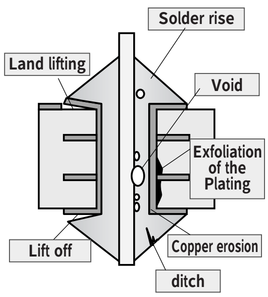
4 Measures for technical issues

The following describes technical issues relating to lead-free products, such as the establishment of the soldering flow process, flow soldering condition settings, design parameters, part evaluation standards, part solder connecting reliability, and measures for heat resistance of circuit board.

4.1 Establishment of flow soldering process

By changing the flow solder material from Sn-Pb to lead-free solder, soldering problems such as those shown in Figure 6 arise.

These problems contradict each other, and require an approach from multiple aspects, such as soldering facilities, soldering conditions, changes in part electrode plating, etc. to solve.



Classi-fication	Problem sympton	content
①	Defect of solder rise	A symptom where the solder does not flow up to the circuit board upper surface due to adrop in solder wettability, or insufficient amount of heat.
②	Lsnd lift-ing	The melting point of the solder is higher than is conventionally,and because the solder co-agulates at high temparatures, circuit board expansion/contraction stresses are applied to the inner walls of lands and through holes, and causes separation from the substrate.
	Exfoliation of through holl plating	
③	Copper erosion	The through hole corner plating is melted by the solder wave , and the remaining plating thickness is reduced.
④	Lift off	A symptom when using solder leveler circuit boards and components with leaded plating. Where the land and solder separates after soldering.
⑤	Void	Voids are incresed due to reduction in solder wettability,and component plating oxidation.
⑥	ditch	The crack by the last coagulating point at the time of solificsting.

Fig.6 Problems in lead-free flow soldering

In lead-free flow soldering, raising of the soldering temperature and extension of dipping time is effective in improving solder rise, but in doing so, the land lifting and copper erosion increases, decreasing reliability.

We will first explain the solder rise and copper erosion, and exfoliation of through hole plating.

There are two types of conventional flow soldering equipment. One is a method where solder is applied by wave flow to the entire circuit board, called a dip flow method. The other is a nozzle method where the solder is applied locally. Initially, evaluations were being made to optimize the conditions in these two methods, but a satisfactory result could not be gained in either one.

In order to balance solder rise and the reduction of copper erosion, a new process was developed where the heat transfer efficiency to the circuit board is raised while suppressing the flow speed of the solder (which has a large effect to the solder erosion).

The relationship of solder rise and copper erosion for the new and conventional two methods are shown in Figure 7.

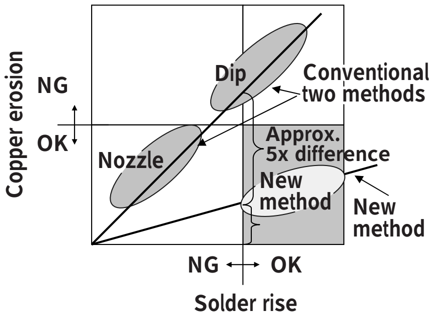


Fig.7 Relationship of solder rise and amount of copper erosion.

By developing a process that balances solder rise and the reduction of copper erosion, it became possible to apply lead-free flow soldering in vehicle mounted products.

Also, it has been confirmed that the plating exfoliation at the through hole can become severe depending on the solder conditions, as shown in Figure 8.

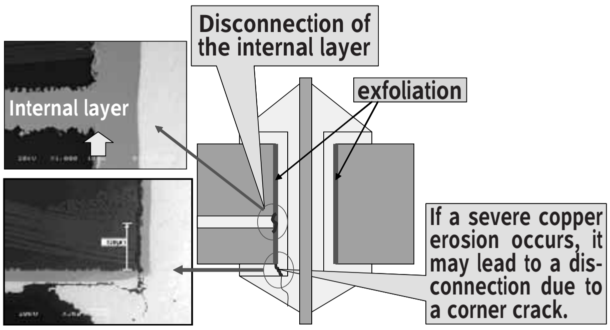


Fig.8 Problem example in through hole soldering

The exfoliation of the plating at the through holes are thought to be caused by the increased shrinkage of the solder during cooling due to the higher soldering temperatures, and because the physical hardness of the soldering material has increased in comparison to leaded solder.

Judgment standards were set for through hole plating exfoliation rates through reliability results, and by managing soldering conditions (temperature, time), the reliability of the product is secured.

Next, the occurrence of whiskers due to re-crystallization of Sn that may arise from the change to lead-free soldering materials and component terminal plating, is described.

Whiskers of the terminal plating are still being investigated and being dealt with. In flow soldering, an occurrence of a whisker was found at the land edge, as shown in Photo 1. Figure 9 shows the occurrence location of the whisker, and it can be seen that it is occurring in the area near the border of the land and substrate, where the solder is thin.

Assuming a whisker occurrence mechanism like that shown in Figure 10, an over-resist covering was applied to the land area so that the land end is not exposed, to compensate.

Photo 1 Whisker

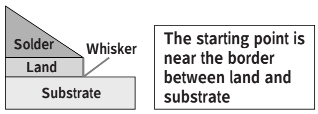


Fig.9 Whisker initiation zone

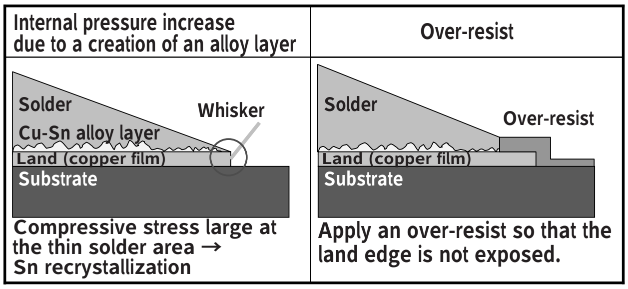


Fig.10 Whisker initiation mechanism and measures

4.2 Part solder wettability and heat resistance

4.2.1 Part solder wetting characteristic

In order to guarantee solder joint strength, it is necessary that an appropriate alloy layer is formed between the base material and the contact surface. Figure 11 shows the solder joint strength drop FTA.

In regards to the soldering characteristics at the part electrode plating, it is known that the solder wettability are adversely affected when changing soldering material from a Sn-Pb solder to lead-free solder. In addition, there is a possibility of a decline in soldering characteristics due to deterioration of the part electrode plating over time, and it is necessary to check whether or not conventional storage control methods are sufficient. There are also differences between part manufacturers in part electrode plating of the same configuration. These types of changes were quantitatively considered, to secure solder wettability.

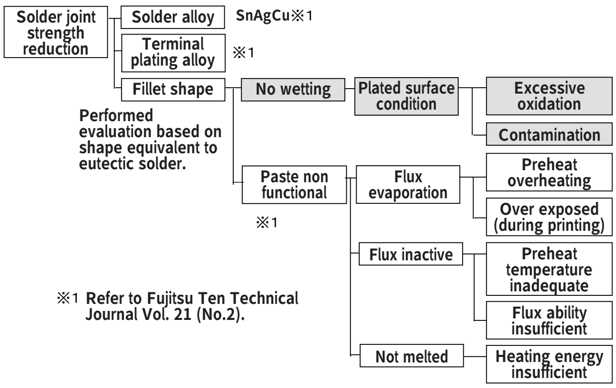


Fig.11 FTA for the strength reduction of the component solder joint

The solder wettability evaluation through the meniscograph utilizes a rapid heating temperature rise method for the evaluation. Figure 12 indicates the rapid heating temperature rise method[4].

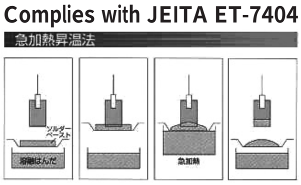


Fig.12 Rapid heating method[4)]

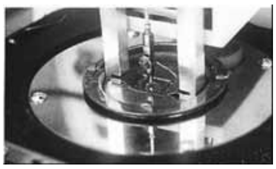


Photo 2 Soaked state

As shown in the micro crucible of Photo 2, the terminal test piece is dipped in the micro crucible, and the solder wettability was evaluated by the amount of wetting force and time. A measurement example of a meniscograph is shown in Figure 13.

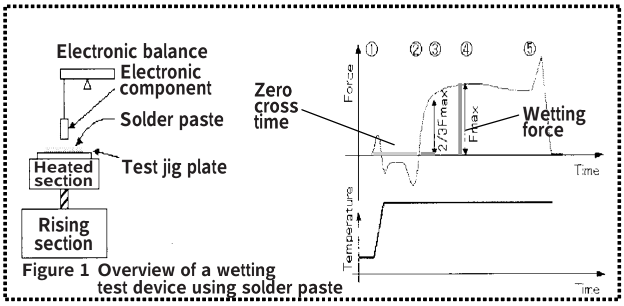


Fig.13 Meniscograph measurement example[5)]

The deterioration of the part electrode over time is greatly affected by the growth of the surface oxide film, and it is important that the solder wettability does not change even in limit conditions of storage. As an evaluation method, the oxide film thickness formed at the limit of storage duration was reproduced through a high temperature/high humidity exposure condition, and the time for this was set as a preprocessing conditions.

Next for Sn-Pb solder and lead-free solder, the zero-cross time and wettability for unprocessed and preprocessed items are measured. The part is determined to be able to maintain solder wettability if the measurement values and the ratio of change before and after preprocessing is within the standard. If it does not fulfill the standard and there is no alternative part, an investigative analysis of the plating was performed at the part manufacturer for improvement.

As indicated by Figure 14, "part electrode plating-caused, solder non-wetting example" there are examples of solder non-wetting due to the condition of part electrode plating. Thus, prevention is implemented by performing the above analysis.

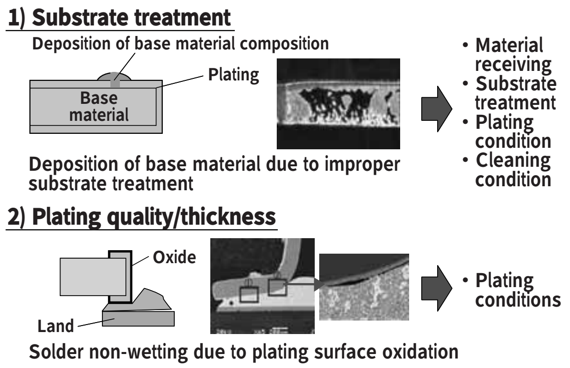


Fig.14 Search example of defect of soldering by plating

4.2.2 Heat resistance of parts

For reflow soldered parts, when the solder material changes from Sn-Pb to lead-free solder, the increase in solder melting point narrows the range from the lower limit of solder melting temperature to the reflow peak temperature, making it impossible to control using the conventional heating methods.

For this reason, it was necessary to raise the heat resistance of parts, and this was requested to part manufacturers. At the same time, we introduced a new reflow furnace which is able to control the temperature of a circuit board evenly, and performed optimization of the reflow profile.

Also, by optimizing part placement in the new product design, evaluation for equalizing the temperature on a circuit board was performed, and by reviewing heat resistance ranking according to different heat capacities from part size and structure, the list of usable components were expanded.

It is necessary to raise heat resistance of part in the same manner for flow soldered parts, and for connectors, it is necessary to change the housing resin material to a high heat resistance material such as SPS[6)].

4.3 Solder connecting reliabilities

If a joint reliability test is performed individually for all newly utilized parts for lead-free products, a massive amount of work and time will be required. Therefore, a selection standard map was created to enable the product designer to select parts satisfying joint reliabilities, to optimize the evaluation.

For vehicle mounted products, a solder connecting reliabilities evaluation was performed through heat cycle testing, using the product operating temperature range and component size as parameters, and by simultaneously performing a part life expectancy simulation, the effect of individual parameters was evaluated. As a result, a lifespan graph for how the solder connecting reliability changes according to the change in usage environment from passenger room mounting to engine room mounting, and from product temperature changes and its frequency depending on the usage condition of the vehicle, was found as shown in Figure 15. From this lifespan graph, it became possible to predict the thermal acceleration factor and the solder connecting reliability of new parts, to evaluate the validity of the joint.

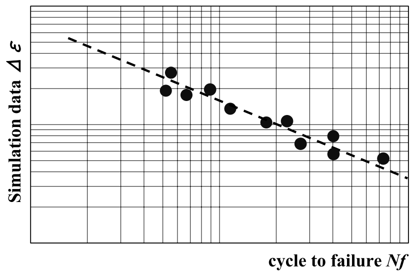


Fig.15 S-N Curve of QFP solder joints

When evaluating a new part, the part shape is modeled using specifications, etc. and a simulation is performed to derive the simulation value ($\Delta\ \varepsilon$). By applying this value to the lifespan graph, the prediction of solder connecting reliability is gained.

Figure 16 shows the flow chart of basis of selection standard map for QFP.

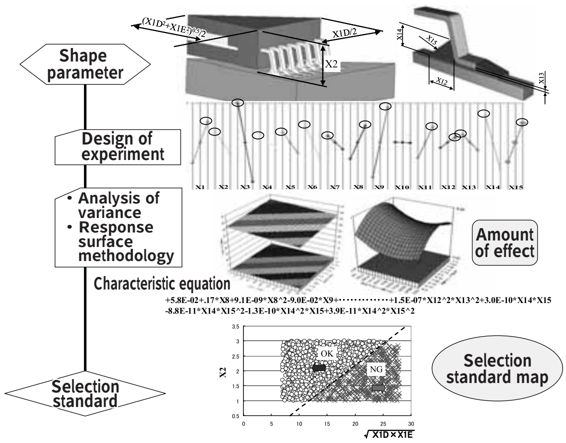


Fig.16 Flow chart of basis of selection map for QFP

In Figure 16, the effect of part shape to lifespan and connecting reliability was predicted using a design of experiments. The parameters utilized for the simulation were reliability testing results and part shape for leading parts that are expected to be used hereafter, and for parameters with large effects, a part selection standard map was created.

Figure 17 shows the relationship between the simulation model and the cross section used in the simulation.

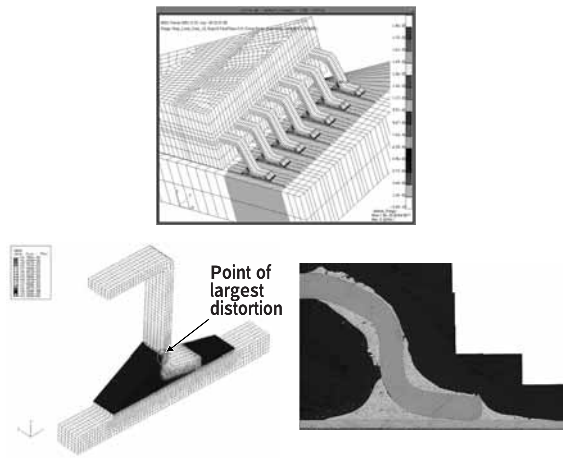


Fig.17 Simulation model and cross section

As can be seen from the above, a part selection guideline was set, and efforts to secure mounting quality are started from the part evaluation stage.

4.4 Heat resistance of the circuit board

The soldering temperature is increased when changing to lead-free solder. Because this temperature is in a higher range than the Tg point of the substrate, a greater thermal load than that for a Sn-Pb is applied. Because of this, various reliability testing for the substrate considering lead-free heat history was performed, and as a result, migration was found in some of the circuit boards due to insufficient heat resistance.

An example insulation reliability testing result is shown in Figure 18.

Testing condition: 85°C, 85%RH, 50V application

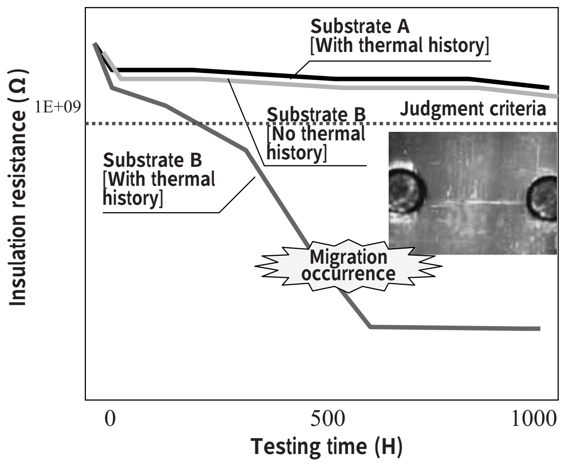


Fig.18 Circuit board thermal history and insulation reliability result

This is thought to be caused by a gap occurring between the glass cloth and epoxy resin due to the heat history, and under the high temperature, high humidity environment, water accumulates and causes migration when voltage is applied.

Figure 19 shows the occurrence conditions of migration.

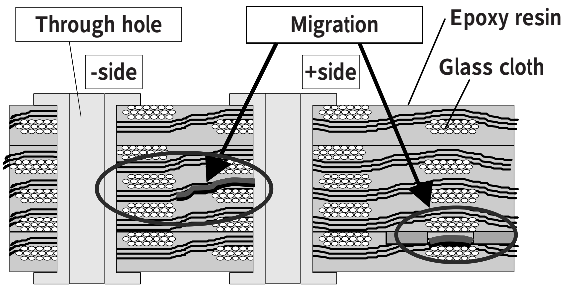


Fig.19 Condition of migration occurrence

For the approval and evaluation of the circuit board, it became possible to secure the reliability of lead-free products by adding testing that considers the heat history.

4.5 Other measures - Development of a low melting point solder material

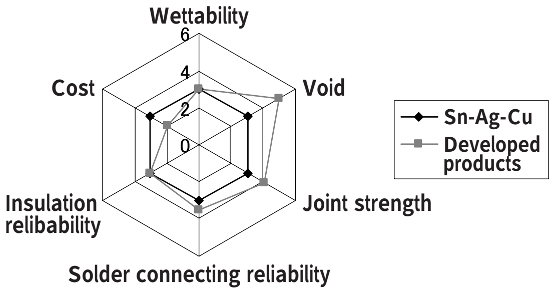
Heat resistance of parts was handled with support from manufacturers, but there are still some parts that are not up to the standard. In order to loosen the heat requirements of the parts, we are also working on developing a lower melting point solder with a melting point closer to eutectic solder.

To lower the melting point of lead-free solder, the typical method is to add Bi, and In.

From mechanical, temperature, and chemical properties of the various materials, In type low melting point solder was evaluated.

A disadvantage of adding In is that the solder deforms at high temperatures, and it is necessary to be wary of the operation guarantee temperatures.

Considering self generated heat of the product, we have determined the amount of In addition that will secure vehicle mounted reliability, and decided on the alloy composition. The developed material shown in Figure 20, has equivalent or better performance as Sn-Ag-Cu solder.



If Sn-Ag-Cu is considered "3",
+1 for every 25% improvement, -1 for every 25% reduction

Fig.20 Comparison of major characteristics with conventional lead-free materials.

Currently, the cost of In is very high, and because a better cost effectiveness against the cost of part heat resistance measures is not gained, actual application has not been implemented.

5 Conclusion

As technical issues for making lead-free products, the establishment of soldering flow processes, flow soldering condition settings, design parameters, part evaluation standards, part soldering connecting reliability, and measures for substrate heat resistance has been described.

From this year, we were able to start lead-free production in all processes including reflow and flow soldering process and are planning to expand its application hereafter.

Recently, some vehicle mounted products are being moved from the conventional passenger room installation to installations in the engine room or direct mount to the engine, exposing them to high temperature operating conditions. Parts and circuit boards are also being required to be even more multifunctional and miniaturized, requiring high density mounting. And because lead-free construction is also required in these products, we will to continue research and development based on reliability securing methods for vehicle mounted products described here, to raise our technical level and for further contribution to the development of automotive technology.

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