

# Evaluation results on reliability of lead-free solder —Tabai Espec efforts to develop viable lead-free solder—

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*As the amount of discarded products from our modern life-style continues to increase, concern has arisen over toxicity to humans from lead leaching out of solder from home appliances and automobiles. Society is becoming aware of the pressing need to eliminate this toxic substance from our products by creating a viable lead-free solder. We at Tabai Espec have undertaken the challenge of creating lead-free solder for use in PCB's to protect the environment. Setting out to obtain basic selection data for the various types of lead-free solder, we have evaluated mounting and reliability of lead-free solder for both reflow soldering and flow soldering. Our results show that the solderability of lead-free solder is inferior to conventional solder, and that for lead-free solder, more study is needed on temperature control in the mounting process as well as on surface treatment of parts.*

## 1. Introduction

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Solder is used as a joining material in printed circuit boards (PCB's) used in discarded home appliances. Concern has arisen over the toxicity to humans from lead leaching out of that solder and into the underground aquifer. Global progress is being made in research on the development and adoption of lead-free solder.<sup>1), 2)</sup>

In Japan, the lead-free evaluation project "Research and development of lead-free solders toward practical solution and standardization" was completed in March 2000 as a consignment project for NEDO (the New Energy and industrial technology Development Organization). The report on the results of that research published findings on mounting processes and mounting characteristics suited to the special characteristics and practical application of the various types of lead-free solder. The report assumes a role of global leadership in promoting the adoption of lead-free solder.

Meanwhile, the fourth draft of a directive proposing the collection and reuse of electrical and electronic parts (WEEE directive: "Proposal for a directive on Waste from Electrical and Electronic Equipment") was published in the EU (European Union) in May 2000. The EU plans to regulate the use of leaded solder from January 2008.

Bills to enact laws regulating the use of leaded solder were studied in the US in 1990, but the US is not currently moving toward regulation. However, research and development for the adoption of lead-free solder was carried out for four years from 1994 by the NCMS (National Center for Manufacturing Sciences), and the NEMI (National Electronics Manufacturing Initiative) began activities in the year 2000. Developments are now under way for promoting the global adoption of lead-free solder.

We at Tabai Espec as well have taken up the challenge of developing lead-free solder for PCB's as a means of reducing the burden on the environment. To promote the use of lead-free solder, we must evaluate reliability of the various types of lead-free solder to obtain basic selection data.

This report presents the results of our studies at Tabai Espec concerning the results of mounting evaluation and reliability evaluation for reflow soldering<sup>\*1</sup> and flow soldering using lead-free solder, and compares this with conventional Sn-Pb eutectic solder. The report also looks at reliability problems encountered when using lead-free solder.

## 2. Tabai Espec efforts to develop viable lead-free solder

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Table 1 shows Tabai Espec activities for the adoption of lead-free solder. Promoting the adoption of lead-free solder requires a high level of scholarship and a serious commitment of time. We at Tabai Espec are participating in the national cooperative "R&D of lead-free solders toward practical solution and standardization". We have also established our in-house "Committee to promote lead-free solder" and set up a site for information exchange between related departments such as production groups and technology groups to study the issue of adopting lead-free solder for use in PCB's. Evaluation methods have been divided into two stages, primary evaluation and secondary evaluation. For primary evaluation, we first produce special-purpose evaluation PCB's for selecting lead-free solder, and we use these PCB's to evaluate reliability and mounting workability. Next, we use actual product PCB's to evaluate the reliability of the lead-free solder selected in the primary evaluations, field test them, and based on those evaluation

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results, we plan to promote the adoption of lead-free solder for successive products targeting the year 2001.

**Table 1 Tabai Espec activities for the adoption of lead-free solder**

Activities	Aims	Schedule			
		1998	1999	2000	2001
1. Participation in the NEDO "Research and development of lead-free solders toward practical solution and standardization"	<ul style="list-style-type: none"> <li>Cooperative research</li> <li>Standardized test methods</li> </ul>		→		
2. In-house establishment and activities of the "Committee to promote lead-free solder"	<ul style="list-style-type: none"> <li>Sharing and dispatching information</li> <li>Proposing development of evaluation devices</li> </ul>		→ Monthly meetings		
3. Primary evaluation using special-purpose PCB's	<ul style="list-style-type: none"> <li>Mounting and reliability evaluation</li> <li>Selecting lead-free solder</li> </ul>		→ Solder selection		
4. Secondary evaluation using product PCB's	<ul style="list-style-type: none"> <li>Developing mounting technology</li> <li>Evaluating reliability</li> </ul>		→ Mounting evaluation	→ Field evaluation	
5. Adopting lead-free solder for products	<ul style="list-style-type: none"> <li>Developing products</li> <li>Reducing environmental burden</li> </ul>			→ Successively adopting lead-free products	

### 3. Evaluation results for reflow soldering, and evaluation results for insulation reliability

#### 3-1 Using special-purpose PCB's to evaluate mounting characteristics

##### 3-1-1 Evaluation solder and mounting conditions

Table 2 shows lead-free reflow soldering materials selected in the primary evaluation. The solder selected, according to currently published data, is basically composed of Sn-Ag materials, with Cu (copper) added to improve solderability and Bi (bismuth) added to lower the melting point.<sup>(5)</sup> The following items were considered in making the selection.

- 1) Confirmation of the above-average reliability of conventional Sn-Pb eutectic solder
- 2) Possibility of using pre-existing equipment (can be mounted in open air atmosphere)
- 3) Confirmation of workability
- 4) Procurement of materials (Even with different types of solder such as paste, rod, and string solder, the same materials can be procured.)
- 5) Cost

Conventional Sn-Pb eutectic solder was also used in these experiments as a standard for comparison. Cost studies were carried out on Sn-Cu (tin-copper) and Sn-Zn (tin-zinc), but we decided to put the matter off due to workability problems and due to the fact that pre-existing equipment cannot be used with the current situation here at Tabai Espec. We plan to investigate these solder materials if future improvement is seen in these areas.

**Table 2 Types of lead-free solder selected**

	Solder type (mass %)	Melting point (°C)
1	Sn-3.5Ag	221
2	Sn-3.5Ag-0.75Cu	216 to 220
3	Sn-2Ag-0.75Cu-3Bi	205 to 218
4	Sn-37Pb (reference)	183

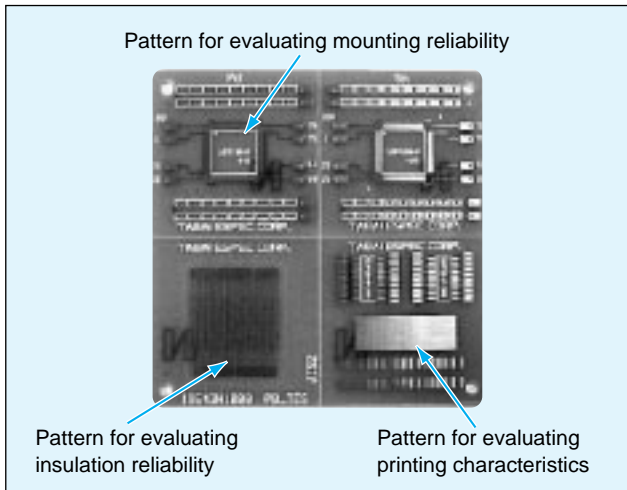
Next, we produced an evaluation PCB for the purpose of evaluating mounting and evaluating reliability (Photo 1). The evaluation PCB was produced to study 1) items for evaluating workability and mounting characteristics, including solderability, printing characteristics, solder bridging, and the Manhattan phenomenon (chip build-up), and 2) items for evaluating reliability, including comparison of plating of parts, joint reliability, and insulation reliability. Glass cloth epoxy (FR-4 equivalent) was used as PCB material, and the PCB measured 100 mm square and 1.6 mm thick. Specifications called for V-cuts in the PCB so that it could be snapped into four pieces for ease of investigation during evaluation and analysis.

**Table 3 Items for evaluating mounting characteristics, and evaluation details**

Evaluation items	Evaluation details
Solderability	Radius and height on PCB to which specific quantity of solder spreads
Printing characteristics	Printing Ease of workability, paste feed, how little seepage occurs
Solder bridging	Number of places neighboring terminals connected with solder
The Manhattan phenomenon	Number of chips composing vertical build-up

To evaluate connection reliability, a 100-pin QFP package<sup>\*2</sup> was mounted using an internal daisy-chain connection<sup>\*3</sup>, and set up for ease of measuring changes in contact resistance due to solder degradation. In addition, to evaluate plating of QFP leads, both Sn-Pb (Sn-10Pb) plating and Pd (palladium) plating were used. Other mounted parts included 2012 type<sup>\*4</sup> chip resistance (0Ω) multiple linked connections and a 20-pin SOP package<sup>\*5</sup>.

A JIS2 type equivalent comb pattern (pattern intervals 0.318 mm) was used to evaluate insulation, and a JIS-Z-3284 specified pattern was used to evaluate printing characteristics and solderability.



**Photo 1 PCB for evaluating reflow soldering**

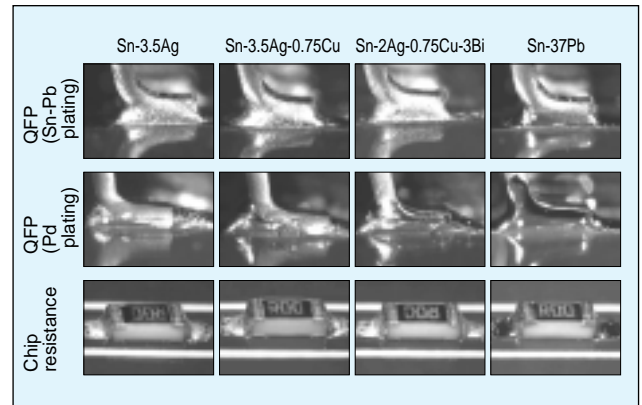
### 3-1-2 Evaluation results for mounting

Based on solder manufacturer data, mounting results were studied and determined for reflow soldering temperature profile settings. Pre-heating temperature for conventional solder is set at approximately 155°C, and the peak temperature is set at approximately 225°C.

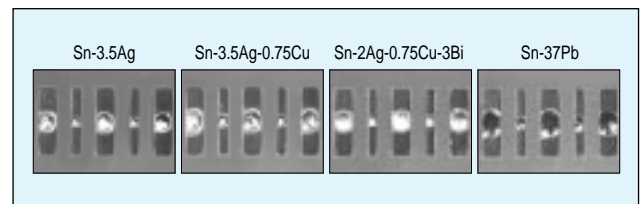
Those temperature conditions are 10 to 15°C higher for lead-free solder, with pre-heating targets set at 165°C and peak temperature targets set at 240°C.

Photo 2 shows the soldered areas for part leads after mounting for the different conditions. Conventional solder shows good wetting for each part, but the lead-free solder with QFP package Pd plating shows poor wetting build-up. The Sn-3.5Ag wetting build-up is particularly bad, and this is thought to be due to its having a melting point higher than the other types of lead-free solder.

Photo 3 shows the results of solder wetting for a copper-plated PCB. Conventional solder has a large area of wetting with a build-up of spread solder to 0.05 mm (n = 20). On the other hand, lead-free solder has a build-up to 0.1 mm with poor spreading. The poor results are thought to stem from the characteristics of the main component of lead-free solder (Sn), as a coating of tin oxide forms and seems to affect the wetting characteristics. Using a reflow process in a nitrogen atmosphere is considered to be an effective method for improving solderability.



**Photo 2 Appearance after mounting**



**Photo 3 Solderability results (after reflow soldering)**

## 3-2 Reliability testing

### 3-2-1 Test methods

Reliability tests for soldered joints were used to evaluate joint reliability and insulation reliability. Using thermal shock (temperature cycle) tests and heat (creep) tests, the main failure modes seen during evaluation for joint reliability were (1) thermal stress failure due to temperature cycles, (2) creep failure due to uniform stress and temperature, and (3) degradation of the solder itself due to temperature assumed to be caused by heat fatigue (e.g., due to metallic diffusion and the growth of intermetallic compounds).

Generally when using temperature and humidity tests, the main failure modes for insulation reliability were (1) insulation degradation due to flux in the solder paste, and (2) degradation thought to be related to water adsorption such as insulation degradation due to the occurrence of ionic migration.

### 3-2-2 Evaluation methods

Methods for evaluating heat fatigue of soldered joints include (1) visually evaluating cracking of soldered joints (external appearance and cross-section observation), (2) measuring changes in conductor resistance, and (3) measuring residual joint strength using a tensile strength test (or pull test). Leadframes such as QFP are pulled upward at a uniform speed at an angle of 45 degrees relative to the PCB as shown in Fig. 1, and the maximum load at the point of rupture is measured.<sup>4)</sup> Other methods for evaluating insulation degradation include observing the external appearance of PCBs with comb patterns and measuring changes in insulation resistance during the tests.

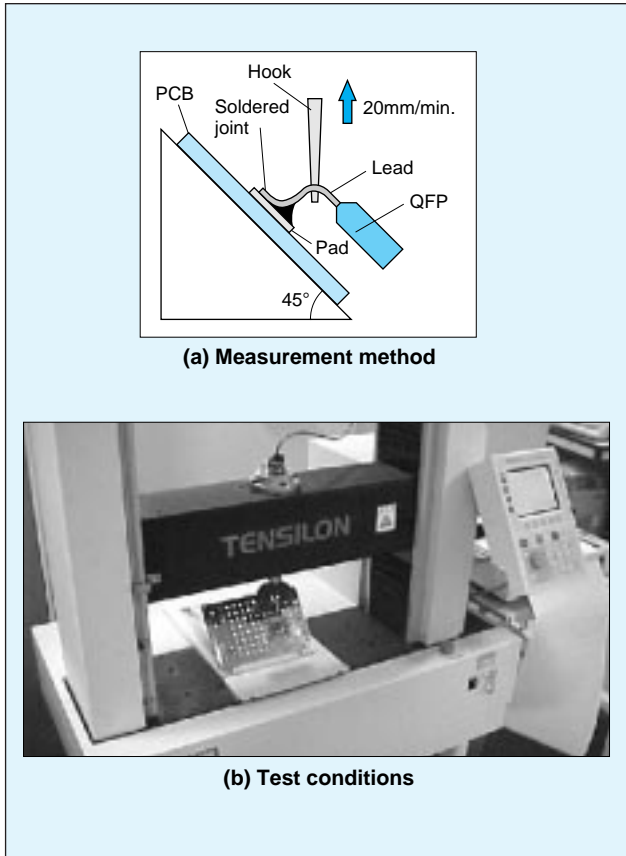


Fig. 1 Measuring tensile strength

### 3-2-3 Test conditions

Table 4 shows the items and conditions in reliability tests. The tests and their related aims covered the following areas. (1) The thermal shock (temperature cycle) tests were used to evaluate deformation in soldered joints caused by differences in coefficients of thermal expansion in the various structural parts. (2) The high-temperature tests were used to evaluate creep fracture caused by heat and metallic diffusion and the growth of intermetallic compounds. (3) High-temperature and high-humidity tests were used to evaluate migration characteristics and flux insulation degradation. Photo 4 shows the test equipment and the system appearance.

Table 4 Reliability test items and conditions

Test items	Test conditions	Evaluation items	Equipment used (all made by Tabai Espec)
Thermal shock test (temperature cycle test)	-40°C ↔ +125°C Dwell time 30 min. 1,000 cycles	<ul style="list-style-type: none"> <li>Changes in conductor resistance</li> <li>Tensile strength</li> <li>Observation of cross-section and external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Thermal shock chamber TSA-100S-W</li> <li>Printed wiring board conductor resistance evaluation system AMR-280P</li> </ul>
High-temperature test	+125°C 1,000 hours	<ul style="list-style-type: none"> <li>Changes in conductor resistance</li> <li>Tensile strength</li> <li>Observation of cross-section and external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Temperature chamber (Industrial oven) PHH-200</li> <li>Printed wiring board conductor resistance evaluation system AMR-280P</li> </ul>
High-temperature and high-humidity test	+85°C, 85% RH 50 V DC applied 1,000 hours	<ul style="list-style-type: none"> <li>Changes in insulation resistance</li> <li>Observation of external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Ultra-low temperature and humidity chamber PSL-2</li> <li>Ionic migration evaluation system AMI-050-P</li> </ul>

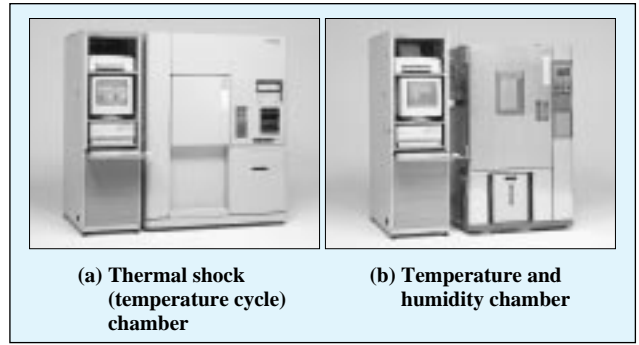


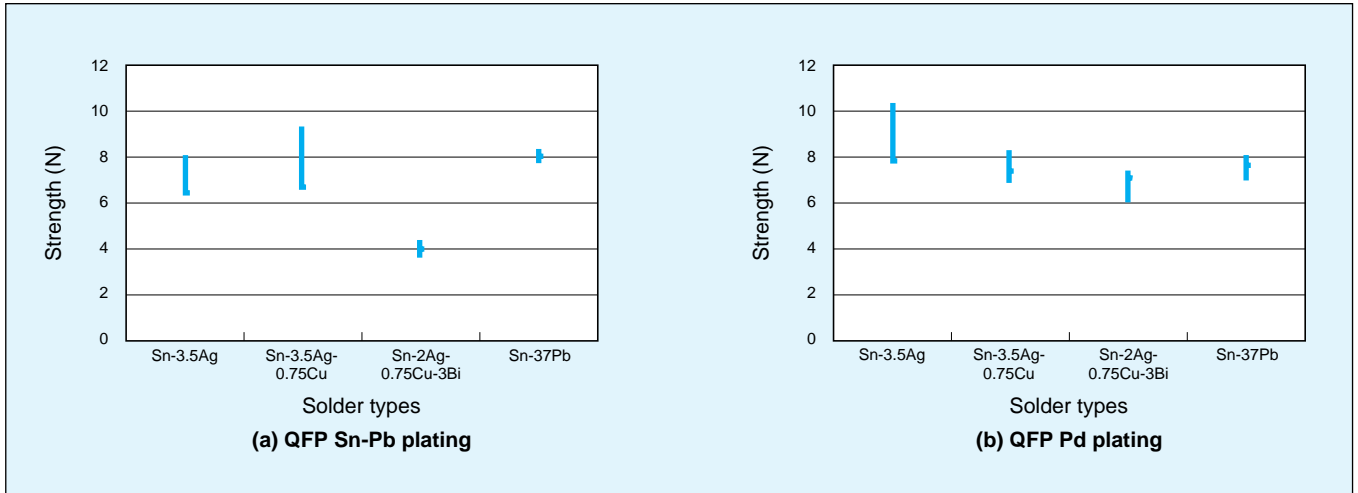
Photo 4 Test equipment

## 3-3 Results of reliability evaluation

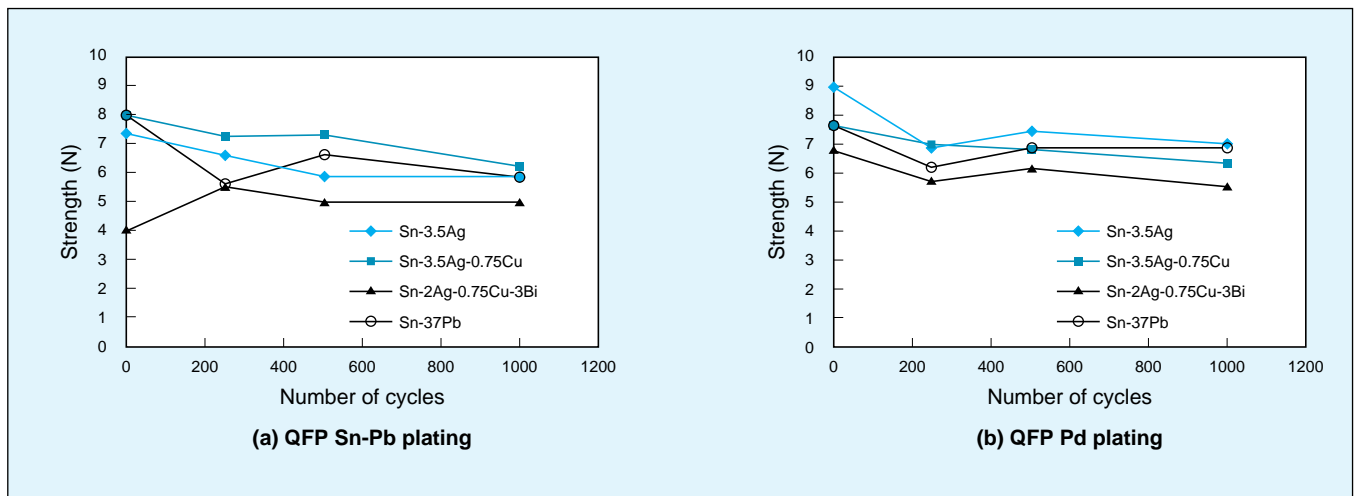
### 3-3-1 Results of tensile strength characteristics

Fig. 2 shows the measurements of initial tensile strength for the Sn-Pb-plated and Pd-plated QFP leads. With the Sn-Pb plating, the Sn-3.5Ag and the Sn-3.5Ag-0.75Cu both showed joint strength tendencies equivalent to or greater than the Sn-37Pb, while plating that included Bi (Sn-2Ag-0.75Cu-3Bi) showed a tendency toward a relative loss of strength. Also, lead-free solder showed more variability in strength than Sn-37Pb, and this is thought to be a result of the solderability of the solder on the leads. On the other hand, Pd plating, including that using Bi (Sn-2Ag-0.75Cu-3Bi) did not show a greater loss of strength than Sn-Pb.

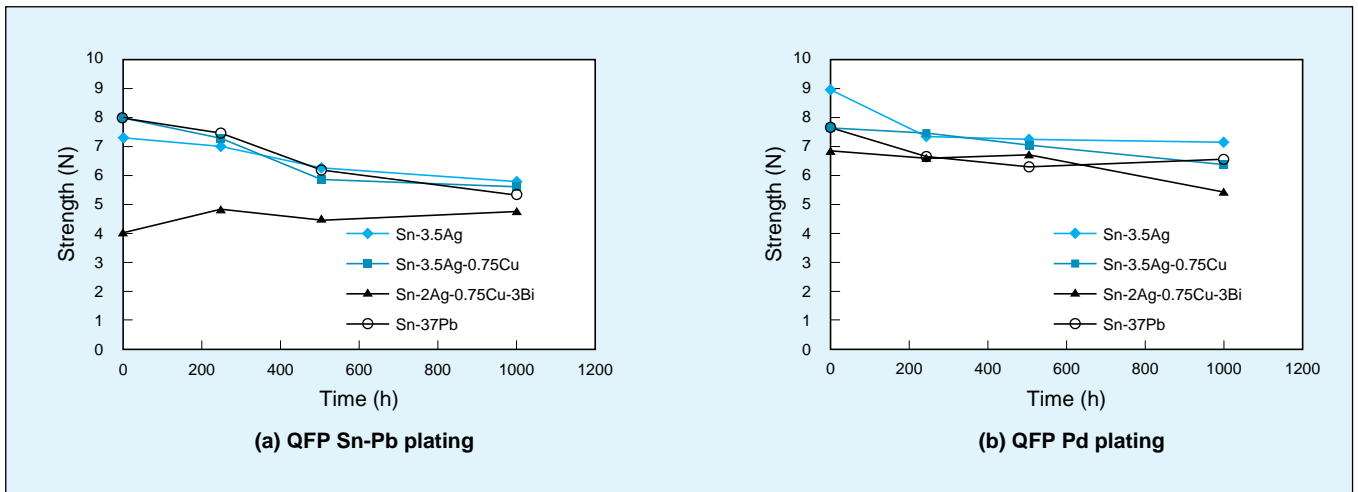
Fig. 3 shows the changes in strength during the thermal shock test, and Fig.4 shows the changes in strength during the high-temperature test. The Sn-3.5Ag and the Sn-3.5Ag-0.75Cu both evidenced similar tendencies of strength loss as the Sn-37Pb in thermal shock tests and high-temperature tests, but the Sn-2Ag-0.75Cu-3Bi showed a greater tendency for strength loss than the Sn-37Pb. The strength loss was especially large in the Sn-Pb plating, and other than the brittleness of the Bi itself, this is assumed to be due to the effects of “low-melting eutectic” with Pb.<sup>5), 6)</sup>



**Fig. 2 Initial tensile strength**



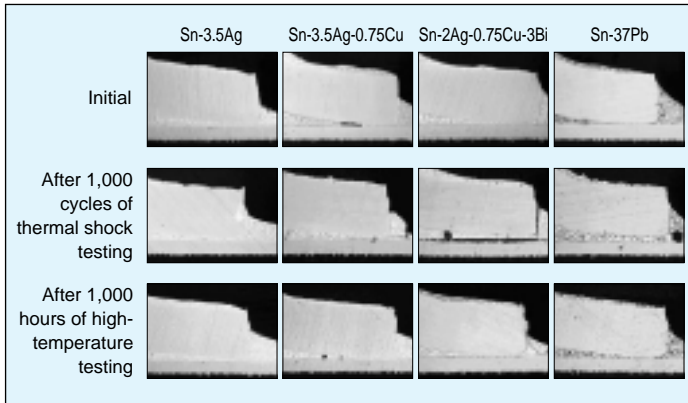
**Fig. 3 Changes in tensile strength after the thermal shock test**



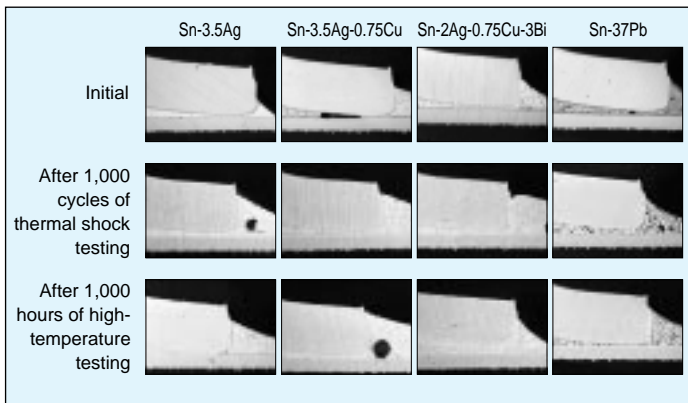
**Fig. 4 Changes in tensile strength after the high-temperature test**

### 3-3-2 Results of cross-section observation

Photos 5 and 6 show initial cross-section observation for Sn-Pb plating and Pd plating on QFP leads and observation after 1,000 cycles of thermal shock (temperature cycle) testing and after 1,000 hours of temperature testing. A finer crystalline structure can be confirmed for lead-free solder than the Sn-37Pb solder in the initial condition. Also, there are a comparatively large number of voids.<sup>6</sup> The reason for the increase in voids is not yet clear, but it is thought to be related to the temperature rise and drop rates during reflow. This must be investigated further.



**Photo 5 Results of cross-section observation of QFP leads (Sn-Pb plating)**



**Photo 6 Results of cross-section observation of QFP leads (Pd plating)**

After each test was concluded, the Sn-3.5Ag and the Sn-3.5Ag-0.75Cu evidenced no recrystallization of structure, and no growth of intermetallic compounds, and were not in a condition leading to cracking. On the other hand, the Sn-2Ag-0.75Cu-3Bi had cracks occurring at the lead connection interface with Sn-Pb only. The Sn-37Pb was not in a condition leading to cracking, but showed progressive recrystallization of the solder structure, which presumably would eventually result in cracking.

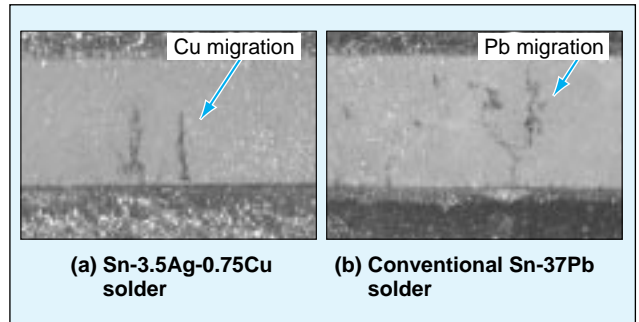
Recrystallization of the solder structure was not seen in the lead-free solder because of the formation of stable compounds due to the fine dispersion of the Ag<sub>3</sub>Sn. Also, there is almost no solid solution of Ag in the Sn, and so once the Ag<sub>3</sub>Sn has formed, reports indicate that it does not become coarse even when exposed to high temperatures.<sup>7), 8)</sup> Sn-2Ag-0.75Cu-3Bi shows conditions leading to cracking with Sn-Pb plating, presumably because (just as with the tensile strength characteristics) the lead

interface may have had a Sn-Pb-Bi low melting point alloy eutectic phase (melting point 99.6°C) which could have impeded the interface reaction to maintain Pb strength.<sup>6), 9)</sup> When using solder with Bi, care must be taken to prevent mixing in Pb from the plated lead parts.

### 3-3-3 Evaluation results for insulation reliability

The insulation evaluation methods used for both reflow and flow soldering<sup>7)</sup> were based on the JIS2 type comb pattern PCBs (conductor intervals: 0.318 mm; medium: glass cloth epoxy; electrodes: copper plating), and four types of solder (Sn-3.5Ag, Sn-3.5Ag-0.75Cu, Sn-2Ag-0.75Cu-3Bi) were used to evaluate reflow soldering. RA flux was used on the comb-pattern electrodes for soldering.

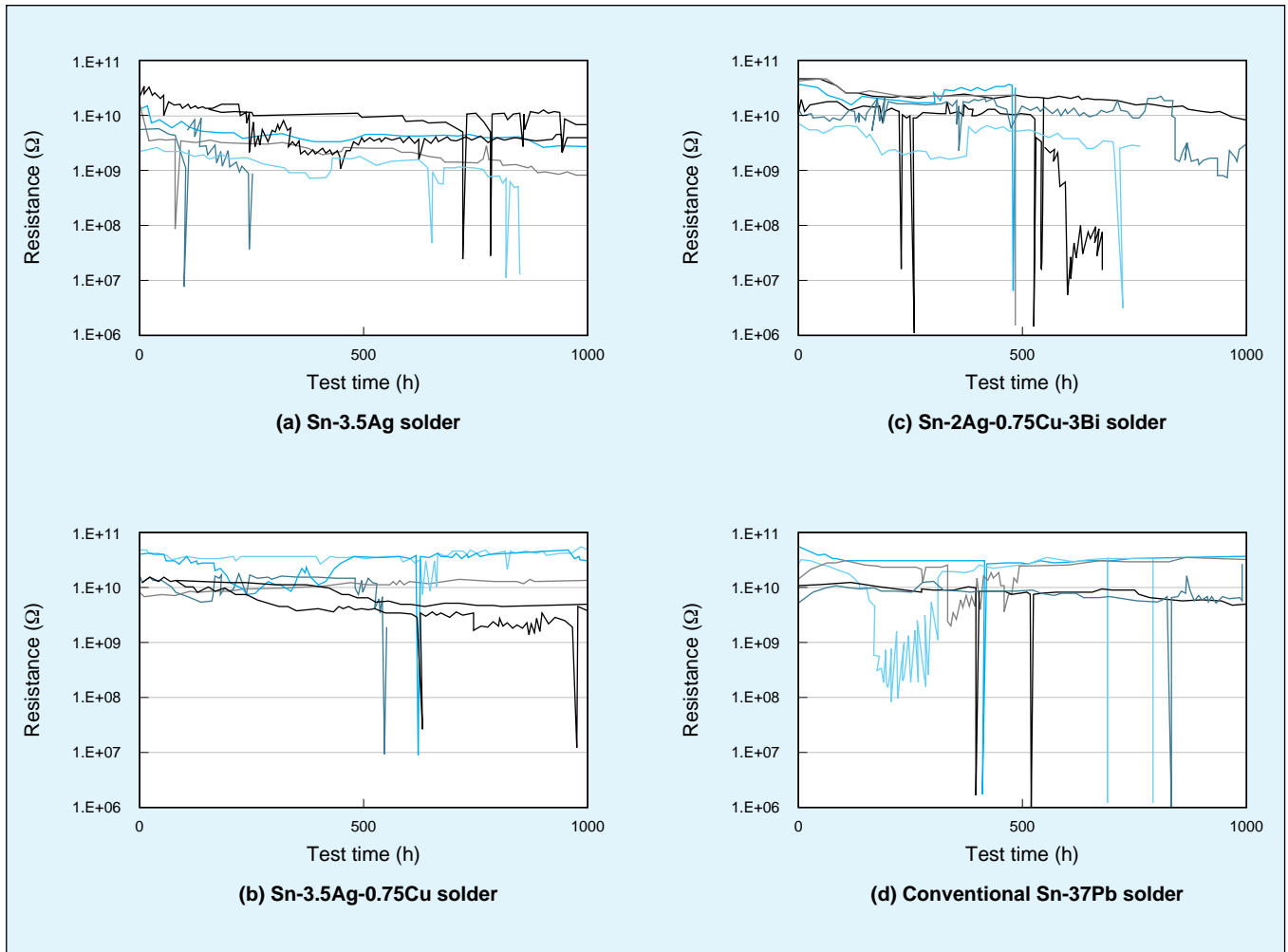
Fig. 5 shows the insulation evaluation results for each type of solder. All solder types showed a drop in insulation resistance during the tests. Post-test observation of external appearance and elemental analysis revealed the occurrence of Cu (copper) ionic migration in the lead-free solder (Photo 7(a)). Conventional Sn-37Pb solder experienced ionic migration of its main component, Pb (Photo 7(b)).



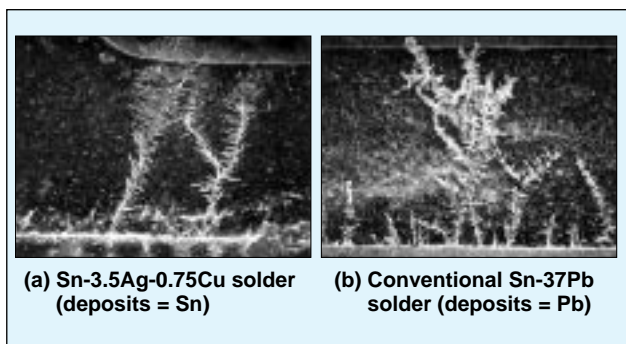
**Photo 7 External appearance after testing**

The sites of Cu migration occurring due to the use of lead-free solder come from the areas not coated by solder. This lack of complete coating is thought to stem from the poor solderability of lead-free solder, resulting in Cu migrating from the substrate metal. On the other hand, conventional Sn-37Pb solder exhibits good solderability on the copper-plated electrodes, providing a good coating on the electrodes, presumably the reason that Cu migration does not occur. With Sn-37Pb, migration originates instead from a component of the solder material.

The migration characteristics of each type of solder material were re-evaluated using a water drop method consisting of uniformly dripping ion exchange water on the electrodes. Evaluation results found a tendency for Pb migration to occur within a short time using conventional Sn-37Pb, while the tendency seen with lead-free solder was to take longer for migration to appear, and the migration component was identified as Sn (Photo 8). The exposed surface of the solder becomes covered with an oxidized film. Unlike conventional Sn-37Pb solder, the main component in lead-free solder is Sn, which forms a more stable oxidized film than Pb. This more stable oxidized film is thought to make lead-free solder somewhat more resistant to migration.<sup>10), 11)</sup>



**Fig. 5** Insulation resistance measurements (n = 10, only one portion of graphs shown)



**Photo 8** Migration caused by water drop method

## 4. Evaluation results for flow soldering

### 4-1 Evaluating PCBs and mounting characteristics

#### 4-1-1 Solder used for evaluation, and mounting conditions used

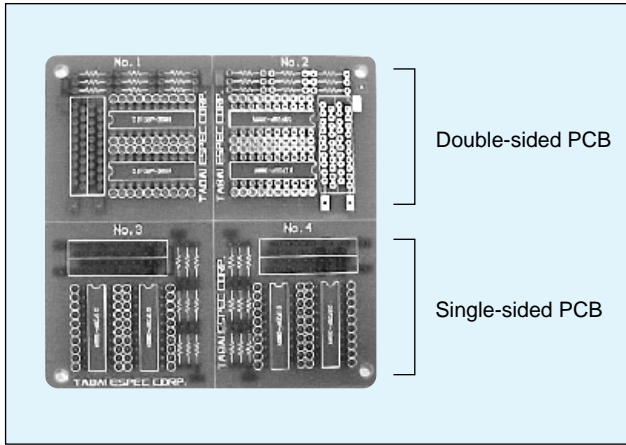
Table 5 shows the composition of the lead-free solder types used to evaluate flow soldering. The same solder types were selected as those used to evaluate reflow soldering. The main component Sn-Ag was used with either Cu (copper) or Bi (bismuth) added, and conventional Sn-37Pb was used as a standard for comparison. Due to difficulties in obtaining the solder with the Bi component, the solder used in these tests contained 0.25 mass percent less Cu and 1 mass percent less Bi than that used for reflow soldering tests.

**Table 5** Solder for flow soldering evaluation

	Solder type (mass %)	Melting point (°C)
1	Sn-3.5Ag-0.75Cu	216 to 220
2	Sn-2Ag-0.5Cu-2Bi	210 to 222
3	Sn-37Pb (reference)	183

Photo 9 shows an evaluation PCB used to evaluate reliability and mounting characteristics. Glass cloth epoxy (FR-4 equivalent) was used as PCB material, and the PCB measured 100 mm square and 1.6 mm thick. A DIP type IC package (2.54 mm pitch width,  $\phi$  1.0 mm) was used as a mounted part, with connectors (2.54 mm pitch width,  $\phi$  0.8mm) and resistors (10 mm pitch width,  $\phi$  0.9 mm). PCBs with double-sided through-hole patterns and PCBs with single-side patterns were created for use with the different parts.

The flow soldering mounting conditions for the lead-free solder were 110°C pre-heat temperature and 240°C peak temperature, approximately 10°C higher than the 100°C pre-heat and 240°C peak temperatures employed for conventional Sn-37Pb solder. The mounting method consisted of spraying on activated rosin flux, then using the single wave jet method for applying the solder.

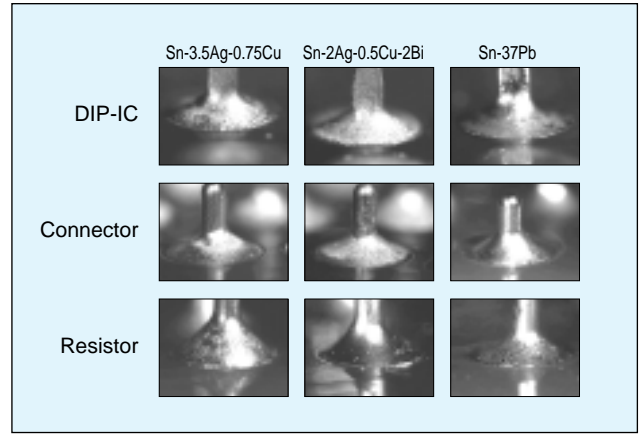


**Photo 9 PCB for evaluating flow soldering**

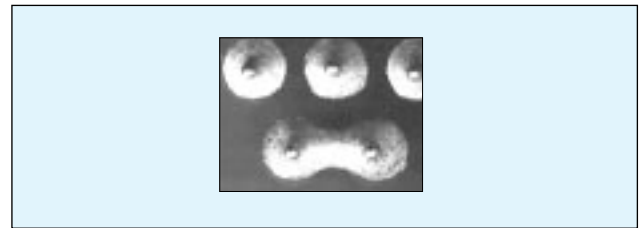
#### 4-1-2 Mounting evaluation results

Photo 10 shows the solder conditions for the parts mounted on a double-sided through-hole PCB. The lead-free solder shows good results for solderability characteristics of all mounted parts compared to conventional Sn-37Pb solder. On the other hand, a lot of solder bridging was seen to occur at the narrow pitch width of the connectors (Photo 11). This is thought to be related to the surface tensile strength of the solder at the time of fusion. Care is assumed to be required in the PCB pattern design, in the direction of soldering, and in controlling the temperature during the mounting process.

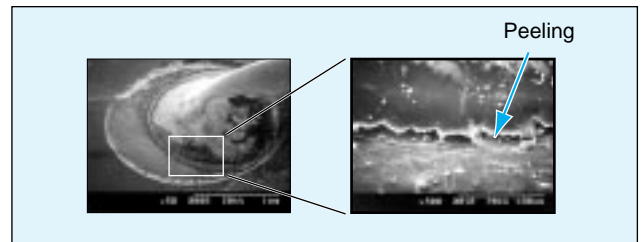
Solder containing Bi showed evidence of lift-off (fillet-lifting) on the surface of the PCB parts side (Photo 12). Lift-off refers to peeling due to segregation of Bi at the interface with the PCB land<sup>8</sup> at the time of solder hardening. Reports indicate that increasing the cooling speed during the mounting process can reduce segregation and prevent lift-off.<sup>12), 13)</sup> The Tabai Espec evaluation also found lift-off occurring only at the PCB parts side, and not occurring on the solder side. Because of this, we believe thermal capacity and thermal conductivity of the various mounted parts causes differences in hardening time, leading to lift-off.



**Photo 10 External appearance after mounting (solder side)**



**Photo 11 Solder bridging**  
(Sn-2Ag-0.5Cu-2Bi, connectors)



**Photo 12 Site of lift-off occurrence, SEM image**  
(Sn-2Ag-0.5Cu-2Bi, resistor surface)

## 4-2 Results of reliability evaluation

### 4-2-1 Test conditions

Table 6 shows test items and conditions for the reliability tests. Tests used to evaluate reliability consisted of high-temperature tests to evaluate changes in solder structure and growth of intermetallic compounds, and thermal shock tests to evaluate the strength of solder bonds under repeated stress. Evaluation items included observing cross-sections and comparing results with Sn-37Pb solder.

**Table 6 Reliability test conditions and evaluation items**

Test items	Test conditions	Evaluation items	Equipment used (All made by Tabai Espec)
High-temperature test	+125°C 2,000 hours	Cross-section observation (removed for observation during test: initial, 250 hours, 500 hours, 1,000 hours, and 2,000 hours)	Temperature chamber (industrial oven) PHH-200
Thermal shock test (temperature cycle test)	-40°C ↔ +125°C Dwell time 30 min. 2,000 cycles	Cross-section observation (removed for observation during test: initial, 250 cycles, 500 cycles, 1,000 cycles, and 2,000 cycles)	Thermal shock chamber TSA-100S-W

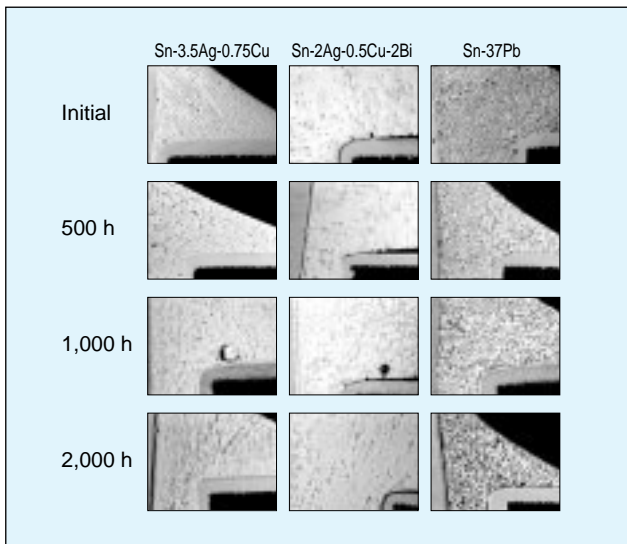
#### 4-2-2 Results of observation of flow soldering cross-sections

Photos 13 and 14 show the post-test cross-section observation results for flow PCBs. Initial conditions showed a finer structure for lead-free solder than for conventional Sn-37Pb solder. Also, lift-off was confirmed at the interface of the solder and PCB part side land with Sn-2Ag-0.5Cu-2Bi solder.

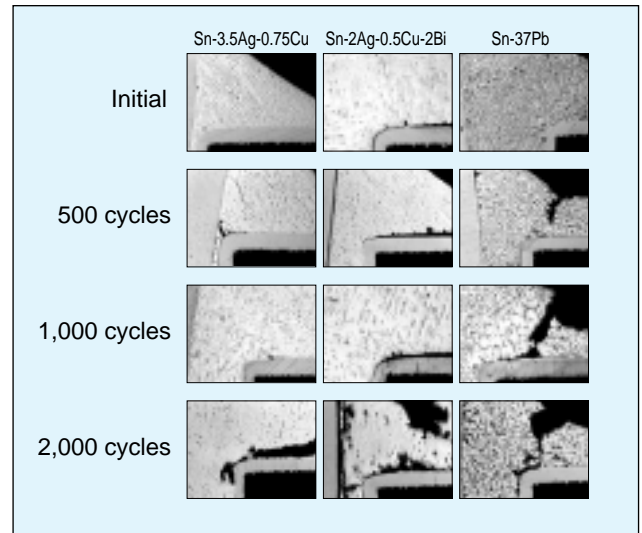
In the high-temperature tests, the Sn-37Pb solder structure became coarser after recrystallizing, but recrystallization was not seen in the lead-free solder. We postulate that, just as in the evaluation results of the reflow soldering, the stable compound  $\text{Ag}_3\text{Sn}$  forms in the lead-free solder, and once  $\text{Ag}_3\text{Sn}$  has formed, the solder does not become coarse even when exposed to high temperatures.

In the thermal shock (temperature cycle) tests, the structure of the Sn-37Pb solder became coarser when the solder recrystallized, just as in the high-temperature tests. After this solder had become coarser, cracks were generated from the solder fillet section<sup>9</sup>, and complete cracking had occurred by 2,000 cycles. No cracking was seen in the Sn-3.5Ag-0.75Cu solder after 1,000 cycles, but cracks were found at the interface between the solder and the PCB land after 2,000 cycles.

The Sn-2Ag-0.5Cu-2Bi solder suffered peeling around the interface between the solder surface and the part leads and PCB land after 2,000 cycles. No progress toward lift-off was seen after 1,000 cycles, but the interface peeling found after 2,000 cycles was believed to have been caused by lift-off.



**Photo 13 Results of cross-section observation after high-temperature testing (500×)**



**Photo 14 Results of cross-section observation after thermal shock testing (500×)**

## 5. Conclusions

The following conclusions were based on the results of mounting evaluation and reliability tests.

- (1) In the presence of thermal stress, the Sn-3.5Ag and Sn-3.5Ag-0.75Cu lead-free solder types showed equivalent or superior reliability to conventional Sn-37Pb eutectic solder.
- (2) Lead-free solder containing Bi suffered a loss of connectivity strength related to surface treatment of parts (mixing in Pb from the parts).
- (3) During flow soldering, lead-free solder containing Bi experienced lift-off (fillet-lifting) due to the difference in solder hardening time related to the thermal capacity and thermal conductivity of the parts.
- (4) Lead-free solder has a much higher resistance to migration than conventional Sn-37Pb solder due to the formation of an Sn oxidation film.
- (5) Lead-free solder has poor solderability, requiring care to prevent migration from substrate metals such as copper.
- (6) The higher solder temperatures for lead-free solder necessitates further study on heat resistance of parts.

## Terminology

### \*1 Reflow soldering

In reflow soldering, the required amount of solder is supplied in advance at the soldering sites, and this solder is then melted using a heat source such as infrared rays, hot air, hot plate, or laser to form a metallic union between both sides.

### \*2 QFP (Quad Flat Package)

The QFP is a type of IC package in which the QFP leads come out from 4 sides of the package and form a gull-wing type (L-shaped) package.

### \*3 Daisy chain

A daisy chain is formed by linking IC package lead terminals and PCBs together in a series. The resistance drop at a single lead terminal pin is slight, and so when evaluating soldered connections, multiple pins are connected and the changes in resistance of these together are measured to find evidence of solder cracking.

### \*4 2012 type

This term is used to express the size of surface-mounted parts such as resistors and condensers. The 2012 size is 2.0 mm (L) × 1.25 mm (W). Other sizes are 3216 (3.2 mm × 1.6 mm), 1608 (1.6 mm × 0.8 mm), and 1005 (1.0 mm × 0.5 mm).

### \*5 SOP (Small Outline Package)

The SOP is a type of IC package in which the leads come out from 2 sides of the package and form a gull-wing type (L-shaped) package.

### \*6 Void

Air bubbles inside the soldered joints are referred to as voids.

### \*7 Flow soldering

In flow soldering, melted solder is flowed onto the PCB to form a soldered joint. The dip method and the injection method are representative types of the molten solder bath.

### \*8 Land

This term refers to a conductor pattern used in attaching and soldering parts. Conductor patterns include such methods as pads for surface mounting and patterns surrounding parts installation holes.

### \*9 Solder fillet

The solder fillet is the form of solder build-up when soldering part leads and lands. It is used to determine whether the appearance of the soldering is acceptable.

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