Approach to lead-free soldering for electric circuit

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1. Introduction

Oriental Motor Co., Ltd. launched the lead-free solder project in November of 1999 in response to the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS Directive) that will be enforced in the EU starting July 01, 2006.

The melting point of the Sn-Ag-Cu lead-free solder system is about 220℃, which is about 40°C higher than that of Sn-Pb eutectic solder (melting point 183°C) that is currently being used, meaning that it cannot be used in the current manufacturing process. Using Sn-Ag-Cu lead-free solder requires more heat resistant parts and a reflow furnace with high-accuracy temperature control.

Oriental Motor implemented a new circuit board manufacturing system that included equipment that could control the temperature accurately enough for the lead free solder reflow process and redesigned our control circuits to incorporate electronic parts that were rated for the required higher temperatures. These changes were implemented in December of 2005. This paper will discuss the activities undertaken by Oriental Motor to switch to a lead-free solder system.

2. Definition and category of a lead-free solder system

The lead-free solder system project goal was to achieve Phase 3 based on the "Definition and category of lead-free" from the lead-free solder's practical use roadmap 2002 (1) of JEITA (Japan Electronics and Information Technology Industries Association).

Definition of lead-free:

The amount of lead contained in a prescribed part to be considered lead-free is assumed to be less than 0.1 % by weight.

Category of lead-free:

Phase 1: Lead-free solder equipment A

At the board mounting stage, lead solder is not used for the PWB (Printed Wire Board) surface finish, solder print, and solder bath, etc. Lead may be contained in the wiring terminals of the parts, inside the parts, and constituent material, etc.

Phase 2: Lead-free solder equipment B

At the board mounting stage, lead solder is not used for PWB surface finish, solder print, and solder bath, and lead is not contained in the wiring terminals of the parts to be mounted. Lead may be contained inside of the parts, and constituent material.

Phase 3: Lead-free solder equipment

In addition to the definition of lead-free solder equipment, lead is not contained in constituent components and/or materials.

3. Lead-free system of control circuit

In a control circuit, places where lead is used includes the PWB surface finish, solder for connection (solder print and solder bath (tank)), external terminals of the electronic parts, and solder for internal connections of the electronic parts. Fig. 1 shows where solder is commonly used in the control circuit.

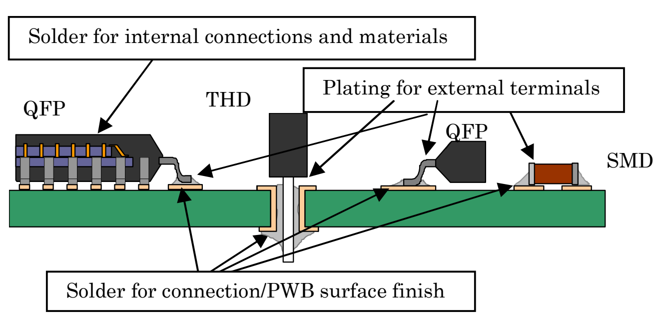

Fig. 1 Places where solder is used

3.1. PWB surface finish

The PWB surface finish was changed from a lead solder leveler to a heatproof preflux or lead-free leveler.

3.2. Solder for connection

As for the solder used for connecting the parts to the PWB, the solder material was changed to meet manufacturing process.

3.2.1. Flow process: Solder bath (tank)

The stick solder used for the flow process was changed from Sn3 7Pb to Sn3Ag0.5Cu.

3.2.2. Reflow process: Solder print

The cream solder used for the reflow process was changed from Sn37Pb to Sn3Ag0.5Cu.

3.3. Mounting parts

By working with each of our electronic part manufacturers and suppliers, we were able to switch to lead-free parts as related to the plating of the terminals, the internal solder connections of the electronic parts, and their constituent materials.

4. Selection of materials

The method used to select the solder materials and the PWB surface finish materials used in the process as follows.

4.1. Solder materials

For the cream solder and the stick solder, etc., an industry standard, high-reliability Sn3Ag0.5Cu solder recommended by JEITA was selected.

4.2. PWB surface finish material

A switch from lead solder to preflux was made. For the selection, the following items were evaluated based on the data from each preflux maker.

4.2.1. Solderability

There must be sufficient solder flow up into the through-hole after two reflow passes on the test PWB (FR-4, 1.6mm thick, through-hole diameter 0.8mm, pad diameter 1.35mm).

4.2.2. Migration test (Note 1)

The deterioration of the preflux doesn't generate any migration, and it satisfies with the insulation resistance test based on the JIS Z3284 Solder paste Appendix 14 Migration test.

(Test condition: 85°C at 85% rh, leaving in a tank at constant temperature and humidity, applied voltage DC50V, and 2,000 hours)

5. Joint Reliability

Table 1 shows the evaluation items for joint reliability.

This section will describe the migration test, soldering strength test based on the thermal, mechanical reliability, and the electrochemical reliability.

5.1. Soldering strength test

As a typical example, the shear load of a solder joint was measured before and after a heat cycle test of the PC board with size 2120 chip parts mounted. The joint reliability was confirmed to be equivalent to Sn37Pb solder.

Table 1 Joint Reliability Evaluation Items

Category	Item
Thermal· Mechanical reliability	Static fracture
	Thermal fatigue fracture
	Creep fracture
	Vibration fracture
	Impact fracture
Electro chemical reliability	Corrosion
	Ion migration
	Electro migration
Others	Sn Whisker(Note2)
	Corrosion Fatigue fracture
	Inter metallic compound

(Note 1) Migration is a phenomenon that occurs when a metal or a metallic compound separates out between patterns of a printed circuit board. When an electric field is applied between electrodes while water in the form of moisture absorption or condensation is present, dissolution and a deposition reaction can occur. This is an electrochemical phenomenon that can cause the metal to grow from the cathode toward the anode.

Table 2 shows the test conditions, and Fig. 2 shows the shear load test of the 2120 size chip parts.

Table 2 Soldering strength test

Solder	Sn3Ag0.5Cu／Sn37Pb
PWB	Test PWB（ FR-4, Thickness：1.6mm）
Conditions	−40～125℃30min　500cycle
Standard	Test methods for lead-free solder -- Part 7: Methods for shear strength of solder joints on chip components

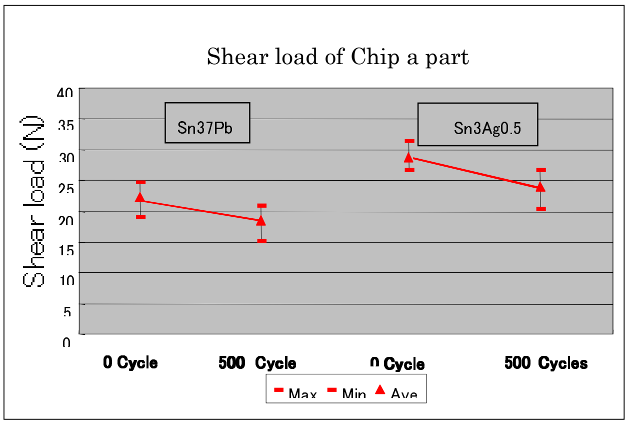

Fig 2 Shear load of 2120 size chip parts

5.2. Migration test

It is confirmed that it doesn't generate the migration, and is satisfied with the insulation resistance by evaluating based on the data of makers of cream solder materials. Table 3 sows the test conditions.

Table 3 Migration test

PWB	PWB (PWB FR-4, Thickness 1.6mm)
Conditions	85℃85% rh、Thermostatic constant humidity chamber. Input voltageDC45V、1000hr.
Standard	JIS Z 3284 Solder paste Annex14 Migration test.

6. Manufacturing process

6.1. Reflow process

Since the melting point of Sn3Ag0.5Cu solder is higher than standard solder, it is necessary to raise the reflow temperature nearly to the temperature rating of the electronic parts. For this reason, a more accurate temperature control system is required. Therefore, a reflow furnace that can control the temperature more accurately was selected for use. For the temperature control profile, a trapezoidal profile was selected based on the size of the parts and the thermal capacity of the PC board. Fig. 3 shows the basic temperature profile used by Oriental Motor.

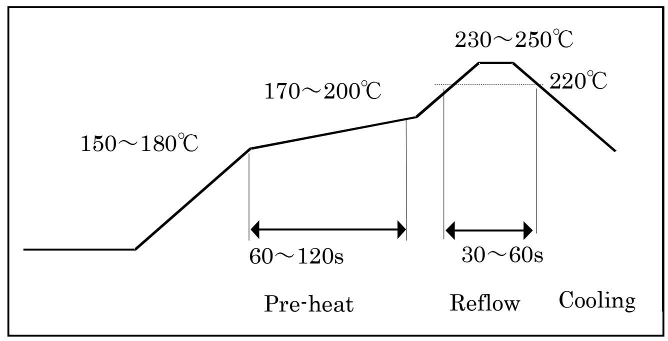

Fig 3 Temperature profile of reflow furnace

6.2. Flow process

As for lead getting mixed in into the solder bath, this was reduced by using lead-free PCB surface finishes and lead-free electronic parts. However, impurities in the solder bath are checked regularly to ensure that the content of lead is less than 0.1 % by weight.

7. Electronic parts

The plating on the terminals of the electrical parts was evaluated based on the data supplied by the electronic parts manufacturers. The actual plating was evaluated for solder wettability, solder strength, and whiskers (Note 2) with four terminal plating types: Sn, Sn-Ag, Sn-Bi, and Sn-Cu when used in combination with Sn3Ag0.5Cu solder.

(Note 2) A whisker is the needle shaped crystal (single crystal in a needle shape) generated from the metals such as Sn and Zn. According to the characteristic of the metal, a distortion arises in the crystal structure when a stress is applied, and the metal changes into an undistorted, larger crystal (recrystallization of the metal) when the distorted crystal reaches a certain temperature (recrystallization temperature). The needle crystal that extends from the metal surface is called a whisker.

7.1. Test of solder wettability

Sufficient solder wettability was confirmed by measuring the time when the wetting starts (zero-crossing time) with 1608 size chip parts by the rapid heating method. Table 4 shows the test conditions.

Table 4 Test of solder wettability

Solder	Sn3Ag0.5Cu／Sn37Pb
Conditions	Soldering temperature：Sn3Ag0.5Cu 250℃ Sn37Pb 230℃
Standard	Environmental testing: Test methods for solderability of surface mounting devices (SMD) by wetting balance using lead-free solder paste

7.2. Soldering strength test

The shear strength of the solder joint was tested before and after the heat cycle test on a PC board with the size 1608 chip parts mounted. The joint reliability was confirmed to be equivalent to Sn37Pb solder. Table 5 shows the test conditions.

Table 5 Soldering length test

Solder	Sn3Ag0.5Cu／Sn37Pb
Conditions	–55～125℃ 30min 1000cycle
Standard	Test methods for lead-free solders -- Part 7: Methods for shear strength of solder joints on chip components

7.3. Whisker test

The whiskers that are generated at the joint of the FFC (flexible flat cable) and the connector were evaluated. After leaving the joint at room temperature, the connector was broken down and examined for the generation of whiskers at each contact by SEM (scanning electron microscopy). The resistance to generation of whisker was determined to satisfactory. Table 6 shows the test conditions.

Table 6 Whisker test

Parts	Connector：Sn Plating、Pitch 1.25mm FFC ：Sn Plating (Whisker resistance spec.)
Conditions	Leaving as joined at room temperature for 2000hr

8. Summary

The transition to a lead-free solder system for control circuits made it necessary for all of the conventional manufacturing processes to be reviewed.

The problems encountered for each step of the process were resolved, the reliability was evaluated, and a lead-free solder mass production system was achieved. Finally, it would have been even more difficult to achieve our goal for a lead-free solder system without the considerable cooperation from our parts suppliers and the new materials that are available.

Reference

(1) JEITA Committee drafting the Roadmap of lead-free solder in practical use: Roadmap of lead-free solder in practical use 2002 Ver.2.1 Japan Electronics and Information Technology Industries Association (2002)

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