Deformation Analysis of Solder Junction by Using of Electromotive Force Method

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Abstract: In printed circuit boards that use lead-free solder, flaking off and the crack in solder junctions are caused by the thermal stress and the impact, and these cause a defective joint. In the present study, it proposes the using of electromotive force method that are able to measure temperature changes caused by deformations of solder junctions as a voltage output. And it is able to understand states of solder junctions. The lead-free solder ball shearing examination by electromotive force method and cross-sectional SEM observation has been done. As a result, it has been understood that the electromotive force of the small size object like the solder ball can be measured, and the deformation assessment of the printed circuit board etc. by the using of electromotive force is effective. Therefore, the practical use of the electromotive force method was examined.
Key words: Lead-free solder; Electromotive force method; Shearing examination

1 Introduction

In recent years, advanced features of information and communication instruments such as mobile phones and personal computers are remarkable. And the miniaturization of these instruments is also progressing. In order to realize these two elements, an integration of electronic devices on the circuit substrate is made high-density. Simultaneously, the package of the semiconductor integrated circuit (IC) module mounted in electronic instruments changed from conventional BGA (Ball Grid Array) and QFP (Chip Scale Package) type to the CSP (Chip Scale Package) type. Therefore, the size of an electrode of IC packages becomes small [1,2].

As the same time, concern about the environmental pollution by contained lead is increasing. In order to prevent environmental pollution, the legal restrictions to the lead used as an electric contact material of electronic instruments are tightened up. Then replacement of electrode contact material is progressing to lead-free solder from lead solder as the measure for environmental regulation. In the mounting substrate that uses lead-free solder, flaking off and the crack in the solder junction are caused by the thermal stress and the impact, which caused the failure of the product itself. Therefore, the basic research about the characteristic of lead-free soldering is required.

In this study, it proposes the using of electromotive force method that can measure the temperature change caused transforming the metallic material to understand deformation behavior of the solder junction as a voltage output [3].

2 Electromotive Force Method

In the electromotive force method proposed in this study, an attachment structure resembles the conventional thermo couple in Fig.1 (a). However, it is noted that there is a quite difference between conventional thermo couple and the electromotive force method. The tip end of the metal wire has adhered on the target respectively as shown in Fig.1 (b). It becomes possible to apply an in-situ observation system into the existing circuit by using this method, as shown in Fig.1 (c).

The electromotive force ΔV which occurs in the case of Fig.1 (b) is called for by (1) type shown below.

$$\Delta V = \alpha_{Cu-SnAgCu} \Delta T1 + \alpha_{SnAgCu-Con} \Delta T2 \quad (1)$$

$\alpha_{Cu-SnAgCu}$ is a relative Seebeck coefficient of Cu wire and solder material. $\alpha_{SnAgCu-Con}$ is a relative Seebeck coefficient of Con wire and solder material. ΔT_1, ΔT_2 become a temperature change of the position to attach, respectively. A Seebeck coefficient is a value peculiar to material, and is Cu; 0.76 mV/K, Con; -3.51 mV/K, and Sn; 0.42 mV/K. Relative Seebeck coefficient $\alpha_{Cu-SnAgCu}$ is 0.34 mV/K, and $\alpha_{SnAgCu-Con}$ is 3.93 mV/K. From a formula (1), when there is no temperature change of the position to attach, electromotive force does not occur. Only when there is a difference, it is thought that electromotive force occurs.

As the advantage of this electromotive force method, it can apply to a small sized thing or a three-dimensional form object, and modification evaluation can target the solder junction itself.

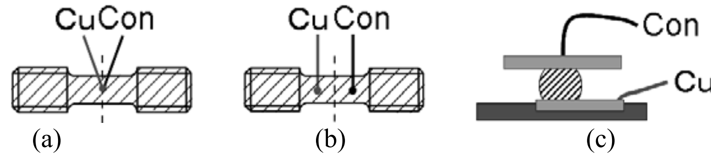


Figure 1 Method of Connecting Thermocouple

3 The Lead-free Solder（Sn-3.0Ag-0.5Cu）Round Bar Tensile Test

3.1 Specimen

Specimen size and shape are shown in Fig.2. Length: 33 mm, the balance of which is 10 mm, and thickness are φ5 mm. A and B are positions to which metal wire connection is attached, respectively, and Cu wire is connected to A point and Con wire is connected to B point. A is the position where a specimen length direction center and B separated 3 mm from A. The quality of the material use Sn-3.0Ag-0.5Cu which is lead-free soldering material.

3.2 Method

Tensile test equipment uses tensile test machine Tensilon (Oriental BALDWIN. make, UMT-25000). It connects with an oscilloscope (the Yokogawa Electric CORP. make, DL1700E) through amplifier (the Kyowa Electronic Instruments Co., Ltd. make, CDV-700A) at measurement of load using a tensile type load meter (Oriental BALDWIN.make, LCP-2), and acquires data. Moreover, in order to measure electromotive force, it measures by a digital multimeter (the ADVANTEST CORP. make, AD7461A), and measurement data is recorded on a personal computer.

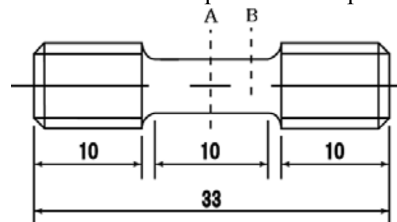


Figure 2 Measure and the Shape of the Specimen

3.3 Results

A measurement result is shown in Fig.3. Condition $_{(1)}$ is the tensile test results of the connection method of the metal wire connection which this study proposed in Fig.3 (a). Moreover, in order to compare, the measurement result in a general thermo couple is shown in Fig.3 (b) as condition $_{(2)}$.

On condition $_{(1)}$, temperature falls according to a thermoplastic effect in an elastic region, and electromotive force is also declining in connection with it. Moreover, in a plastic region, generation of heat by plastic distortion energy shows that the rise of electromotive force has taken place. The waveform of condition $_{(2)}$ of the same electromotive force as condition $_{(1)}$ also corresponds, and the maximal electromotive force value shows the same value as 0.016 mV.

It is thought that the measurement by the metal wire connection which detached the thermo couple proposed by this study from the above thing is possible.

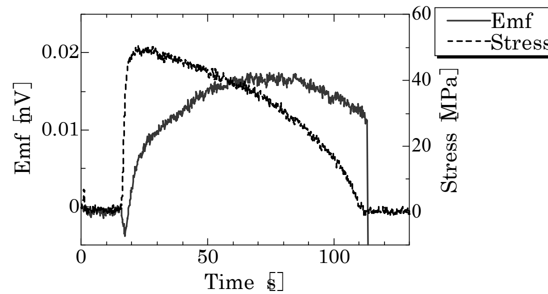
4 The Lead-free Solder Ball Shearing Examination

4.1 Specimen

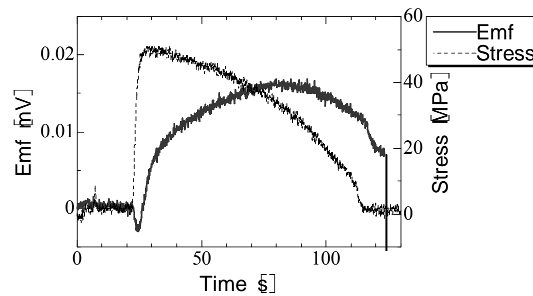
The specimen is a single electrode to suppose including the metal wire connection proposed by this study in an actual product circuit. The creation procedure etches the Photosensitive Circuit Board (Sunhayato CORP. make, NZ-P 12K), and processes it into the size shown in Fig.4 (a). The Constantan is also processed into the size shown in Fig.4 (a). And lead-free soldering paste (Nihon Almit Co., Ltd. LFM-48 U TM-HP) is attached in the center of a substrate, a solder ball is carried on it, and surface mount equipment (LPKF ZelFlow R04/R04N) performs reflow soldering.

Then, reflow soldering of the substrate and the Constantan is carried out using a guide. The specimen shown in Fig.4 is created. At this time, the guide that a substrate and the Constantine board become parallel is created, and reflow soldering is performed using it. Reflow soldering conditions are shown in Table.1. Moreover, the quality of the material of a substrate uses paper phenol, and a lead-free

soldering ball uses Sn-3.0Ag-0.5Cu.

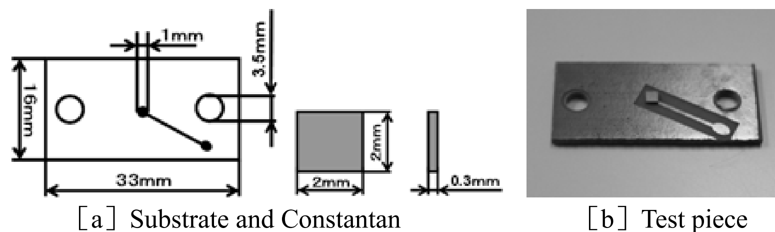


(a) Condition $_{(1)}$ Emf and Stress



(b) Condition $_{(2)}$ Emf and Stress

Figure 3 Measurement Result



［a］Substrate and Constantan ［b］Test piece

Figure 4 Specimen Geometries

Table 1 Reflow Soldering Condition

	Waste heat		Heating	
	Temperature[C]	Time[s]	Temperature[C]	Time[s]
Lead-Free Solder	180~200	180	250	50
Con electrode	210	300	250	200

4.2 Method

Shearing examination equipment uses Micro Tester (INSTRON CORP. make, model 5948). This examination fixes the substrate which connected the thermo couple, and gives displacement according to shearing force of the test equipment. And the temperature change which arises in connection with the deformation is measured as a voltage output by the Seebeck effect.

The tensile type load meter (Oriental Baldwin LCP-2) is used for measurement of load. And it is made to output to a PC through amplifier (Kyowa Electronic Instruments Co., Ltd. make, PPM-712B), and is measured automatically. Moreover, in order to measure electromotive force, it measures by a digital multimeter (ADVANTEST CORP. make, AD7461A), and measurement data is recorded on a PC.

4.3 Results

The result of having done the lead-free solder ball shearing examination by shear rate 1 mm/min is shown in Fig.5. At first, both load and electromotive force go up from the amount of displacement in

0.02mm. This is considered that the rise of electromotive force take place by generation of heat according to plastic strain energy. And since the solder separates from a copper land at the amount of displacement in 0.45mm, it is considered that a rapid change of electromotive force take place.

Moreover, electromotive force is stabilized from the amount of displacement in 0.1 mm. Next, the result of cross-sectional observation of a junction interface is shown in Fig.6. Fig.6 (a) is a SEM image of the interface constantan and the solder ball. And Fig.6 (b) is a SEM image of the interface of the solder ball and Cu land.

An intermetallic compound layer and void can check Fig. 6 (a) and (b). There is character in which this intermetallic compound layer is hard and weak. It becomes a cause which exfoliation produces in connection with modification. Distortion of a junction is eased because exfoliation arises. That is, generation of heat by distortion is controlled. Therefore, electromotive force is stabilized from the amount of displacement in 0.1 mm. Moreover, from the lead-free solder ball shearing examination, infinitesimal deformation can be taken out as a voltage output and it is considered that the application to a mounting substrate is also possible.

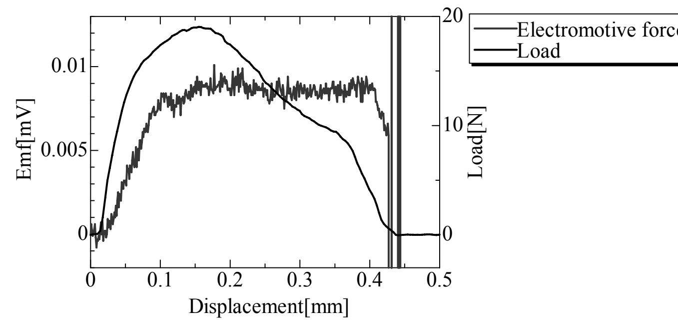
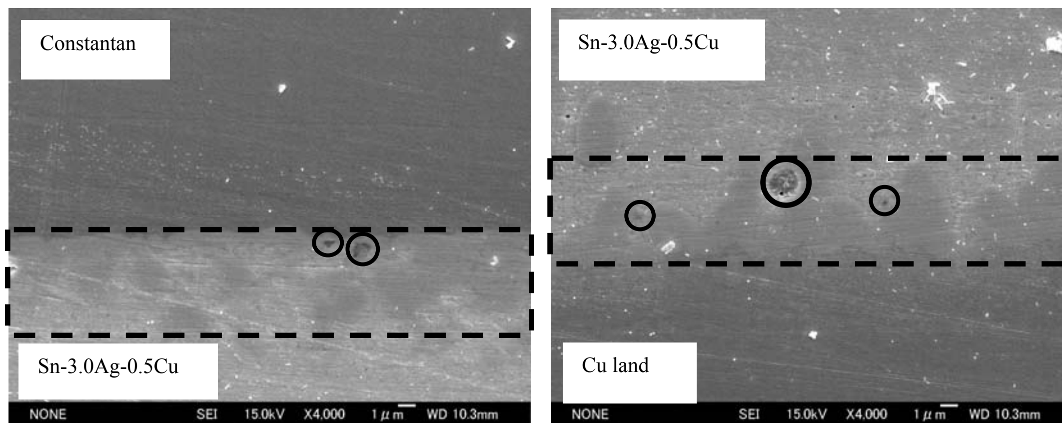


Figure 5 Experiment Result



(a) Constantan – Solder ball (b) Solder ball -Cu land

Figure 6 Cross Sectional SEM Images of Junction Interfaces

5 Conclusion

From the lead-free solder round bar tensile test, temperature falls according to a thermoelastic effect in an elastic region, and electromotive force is also declining in connection with it. And in the plastic region, generation of heat by plastic distortion energy shows that the rise of electromotive force has taken place. Moreover, it is considered that the electromotive force measurement by the metal wire connection which detached the thermo couple proposed by this study is possible.

From the lead-free solder shearing examination, the fall of the electromotive force in an elastic region cannot be checked. The rise of electromotive force can be checked in a plastic region. Moreover, infinitesimal deformation can be taken out as a voltage output and it is considered that the application to a mounting substrate is also possible.

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