Thermal Fatigue Assessment of Lead-Free Solder Joints

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ABSTRACT

In this paper the authors have investigated the thermal fatigue reliability of lead-free solder joints. They have focused their attention to the formation of the intermetallic compound and its effect on the initiation and propagation behaviors of fatigue cracks. Furthermore, they also studied the effect of voids in the solder joints on the fatigue reliability.

An isothermal fatigue test method was used in this study to improve the efficiency of fatigue study, and several different lead-free solder alloys, Sn-Ag-Cu, Sn-Ag-Cu-Bi, Sn-Cu and Sn-Zn-Bi were investigated. There are two kinds of fracture mode in lead-free solder joints, one is solder fatigue mode, and the other is an interface fatigue mode. Based upon the experimental results, it was found that the mode transition of the fatigue crack is affected by not only the properties of the intermetallic layer but also the tension strength of the solder material. If the tension strength is lower than a critical value, the fatigue cracks in the solder joints appear within the solder domain, that is the solder fatigue mode, and their fatigue life can be assessed by Manson-Coffin's law of the bulk solder material. On the other hand, if the tensile strength is higher than that value, the interface between solder and Cu pad breaks much earlier than the solder fatigue life, that is the interface mode.

The authors have found if Sn-Zn-Bi is used with another Pb-free solder material, a kind of composite structure can be built during the reflowing processes. In this study, the mechanical fatigue strength of this kind of Sn-Zn-Bi solder joint was studied. Based upon the results of mechanical shear fatigue test and FEM(Finite Element Method) analysis, it was found that if Sn-Zn-Bi was used as reflow solder with Sn-Ag-Cu ball, the CSP solder joints are as reliable as the pure Sn-Ag-Cu CSP. This is because Sn-Zn-Bi solder paste and Sn-Ag-Cu solder ball did not melt together completely and formed two-layer structure, and this two-layer structure reduces the stress concentration at the joint corners, and prevents successfully the occurrence of the interface cracks. As a result the fatigue life of Sn-Zn-Bi/Sn-Ag-Cu CSP is equivalent to that of Sn-Ag-Cu joints.

The other new problem is that voids are very easily formed in lead-free solder joints during the reflow process, and the effect of the voids on the fatigue strength of solder joints has attracted attention. In this study, the relationship between the voids and fatigue strength of solder joints was examined using mechanical shear fatigue test. Using the mechanical shear fatigue test, the effect of the position and size of voids on fatigue crack initiation and crack propagation has been investigated. It was found the fatigue life of solder joints is affected not only by the size of the void but also by its location. But if the size of the void is lower than a limit its effect will become negligible.

INTRODUCTION

Recently surface mount technology such as, BGA (Ball Grid Array), CSP (Chip Size Package), and flip chip, has been adopted in many electric and electronic devices such as computers, household electric appliances, and so forth. The tendency of recent developments in electronic components is characterized by miniaturization, performance enhancement, and the high pin count of the package. At the same time, there have been serious debates about the environmental problem where Pb should be removed from the solder joints. Debates are now developing to a remarkable movement to establish regulations for the removal of Pb, especially in European countries and Japan. Therefore, many studies have been aggressively promoted to develop technologies for replacing Sn-Pb solder with lead-free ones.

The authors have studied and established the evaluation method of thermal fatigue strength for the BGA structure of the Sn-Pb eutectic solder [1]-[10]. With recognition growing about lead-free solder materials, it became clearer that conventional Sn-Pb eutectic solder has many merits such as a low melting point, good wettability and high electric and mechanical reliability, and it is very difficult to find a lead-free material that has superior or comparative characteristics compared with the eutectic solder. At the moment, the most favorable candidates for the lead-free solder materials are Sn-Cu for the flow soldering, and Sn-Ag-Cu, Sn-Ag-Bi and Sn-Zn-Bi for the reflow soldering, because using these kinds of lead-free solders can achieve almost as close a reliability level as using Sn-Pb eutectic solder. However, it is anticipated that the intermetallic compound formed by the thermal fatigue cycle will seriously affect the thermal fatigue strength under some special conditions [11]-[12].

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The authors have paid attention to the intermetallic compound formation between the solder bulk and the Cu-pad due to thermal cycling, in Sn-Ag-Cu (Bi), Sn-Cu and Sn-Zn-Bi lead-free solder materials [11]-[15]. They have discussed the relation between the intermetallic compound and the thermal fatigue strength and the relation between the mechanical properties of solder materials and the fatigue failure modes of the solder joints.

There is the serious problem that voids are easily generated in lead-free solder joints during the reflow process as compared with Sn-Pb eutectic solder. The reason why the voids are formed in the lead-free solder joints seems to be related to the rise and fall time of temperature during the reflow process, but the effect of voids on thermal fatigue reliability of lead-free solder joints is still unknown. Therefore, the mechanical fatigue tests of CSPs (Chip Size Packages) were carried out in order to compare the fatigue strength of solder joints in which voids exist and solder joints without voids. The authors examined the relation between the formation of voids and the fatigue strength of solder joints based on the results.

INTERMETALLIC COMPOUND AT THE INTERFACE SODLER OF SOLDER JOINTS

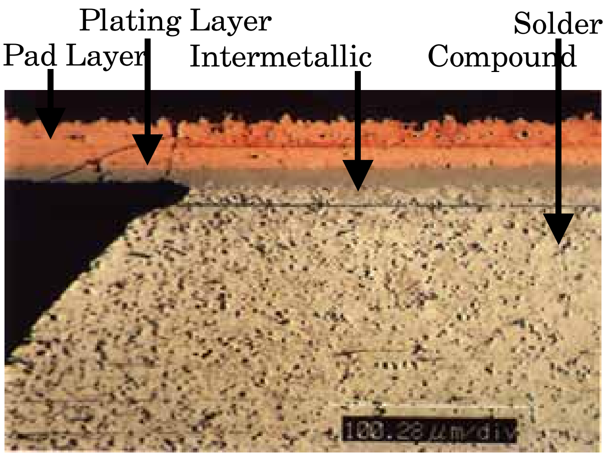

Fig.1 Structure of solder joint

Figure 1 shows an enlarged view of the microstructure around the interface of a solder bulk material and the Cu-pad. The intermetallic compound is formed at the interface if the Cu-pad is not plated by Ni, and the components of the compound are Cu-Sn (Cu6-Sn5 or Cu3-Sn) for the case of eutectic solder and Sn-Ag-Cu (Bi). The fatigue fracture mode of the solder joints in which the intermetallic compound is remarkably formed depends upon the solder materials, processing conditions, testing conditions, and so forth.

The fracture modes can be roughly classified into the following three types:

(1) The first case is a fatigue fracture in the solder bulk layer, it is called solder fatigue failure mode in this study. It is caused by the low cycle fatigue due to the repeated nonlinear strain range. For this case, the fatigue life assessment can be carried out by using Manson-Coffin’s law as a basis [3].

(2) The second is a fatigue failure mode in the intermetallic compound layer or at the interface of the intermetallic compound and the solder material. It is called interface fatigue mode. This failure mode is caused by the decrease of ductility due to the growth of the intermetallic compound layer.

(3) The third is a peeling failure mode of the Cu-pad from the printed circuit board. This is caused by the stress concentration. The criterion for the strength assessment is now under investigation.

Furthermore, for the mode (2), the factors affecting to these fracture mode can be estimated as follows:

(1) The reasons for failure in the intermetallic compound layer are the followings

· Growth of the intermetallic compound under the reflow process;

· Growth of the intermetallic compound due to the dwell time at high temperature during the thermal fatigue test;

· Repeated stress concentration at the intermetallic compound layer at low temperature during the thermal fatigue test.

(2) The reasons for failure at the interface of intermetallic compound and the solder layer are the followings

· The growth of the intermetallic compound and the repeated stress concentration;

· The coherency of the grain boundaries between the intermetallic compound and the solder bulk.

It was found by the experimental results that it scarcely happens that the different fracture modes arise simultaneously. In almost all cases, only one mode of fracture is dominant. Therefore, it is important to investigate the conditions under which each fracture mode dominantly occurs. It has been found that the failure modes can be controlled and then a good guideline can be acquired to develop a new solder material and soldering process. In this paper the authors have paid attention to the difference of fracture mechanism of the solder joints, and they investigated the initiation criteria of each fracture mode and the effect of the mechanical properties of solder material on these failure modes.

MECHANICAL FATIGUE TESTING EQUIPMENT

Until now, the isothermal mechanical fatigue test was proposed to evaluate the fatigue reliability of the Sn-Pb solder joints instead of the thermal cyclic test by the author’s group and the other groups [7],[8], [10], [11],[16]. It has been confirmed that the fatigue life of solder joints under power cycling can be predicted by the same Manson-Coffin’s curve given by the isothermal mechanical fatigue tests. Furthermore, the shift of the failure modes can be checked by comparing the experimental results of the fatigue life with the value predicted from the fatigue life curve for the solder failure mode. If the fatigue life of a solder joint is much shorter than the predicted value, that means the failure mode has changed from the good solder failure mode to the interface failure mode or the other bad mode. The consistency of these two kinds of test methods has sufficiently been taken for the Sn-Pb solder joints case, where the failure mode was almost always the solder fatigue mode. However, the growth of the intermetallic compound in high-temperature dwell time must be considered, because the interface failure mode may become one of the major modes,

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when a lead free solder material is used. In this study in order to investigate the interface fatigue behavior using the isothermal fatigue test method, a specimen with lead-free solder was heat-treated before the test to accelerate the growth of intermetallic compound. And then the cyclic mechanical deformation was directly given to the specimen to measure its fatigue life.
Figure 2 shows the schematic illustrations of isothermal mechanical fatigue test equipment used in this study. The specimen was fixed to the jigs by bonding both upper and lower surfaces. Then cyclic shear displacement was applied repeatedly to the upper jig. A displacement controlled fatigue test was carried out by applying triangular waves with a constant displacement rate. The cross sections of the solder joints were observed through a microscope with high magnifying power (maximum to 3000 magnifications on the display) during the whole fatigue cycles. And the relative displacement on the upper and lower surfaces of the solder ball, $\Delta\delta_{re}$, was measured directly and automatically by the digital microscope system. Although, there could be some different definitions for the number to failure N_f, in this study, it was defined as the number of cycles when the load measured by a piezo type load cell drops about 10% from the initial level of the reaction load. And in order to investigate the stress and strain behavior in the solder joint under the mechanical cyclic loading, the analytical code ANSYS was used to carry out the elasto-plastic analyses.

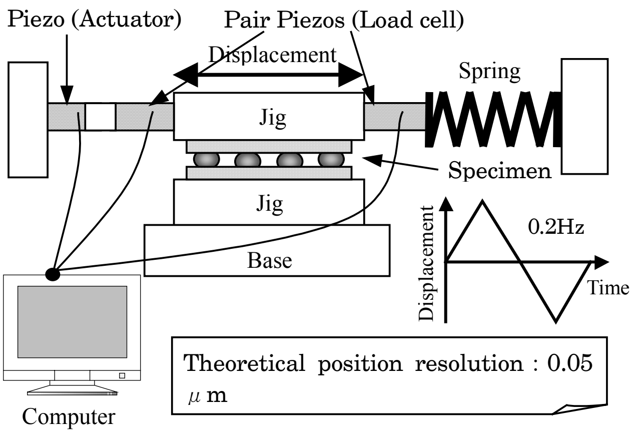

Fig. 2 Isothermal fatigue-testing equipment

RESULTS OF MECHANICAL FATIGUE TEST

In this study, shear type mechanical fatigue tests were used to examine the failure modes and fatigue strength of the lead free solder joints. Figure 3 shows the structure of a shearing type solder joint. Because the width is much longer than the height of the solder layer, this kind of solder joint could prevent the stress and strain concentrations at the edge of the solder layer. The lead-free solder materials used in this study are Sn-Cu-Ni, Sn-2.9Ag-0.5Cu-3Bi, and Sn-8Zn-3Bi. These specimens were heat-treated before the test by holding at 150ºC for 200 hours to accelerate the growth of intermetallic compound as in the thermal cycle test. And the specimen of Sn-8Zn-3Bi was heat-treated by holding at 110ºC for 300 hours. The fatigue life of each solder joint was

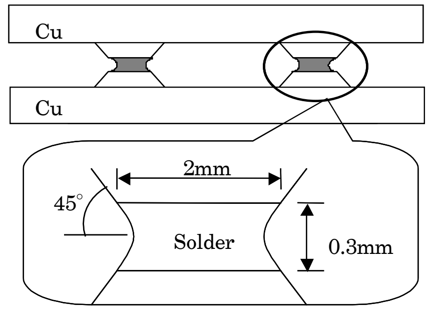

Fig.3 Structure of shearing type specimen

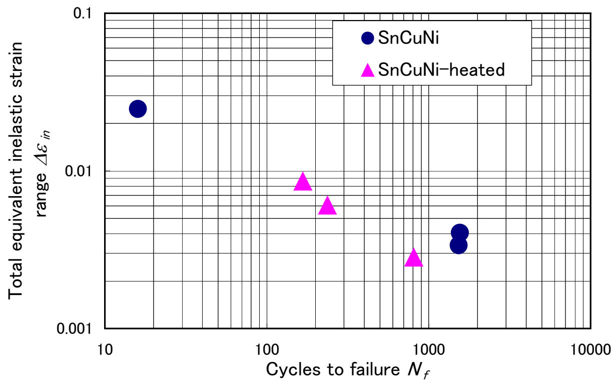

Fig.4 S-N curves of Sn-Cu-Ni solder joints

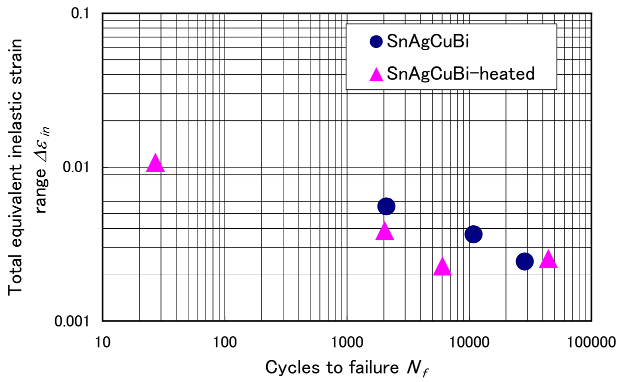

Fig. 5 S-N curves of Sn-2.9Ag-0.5Cu-3Bi solder joints

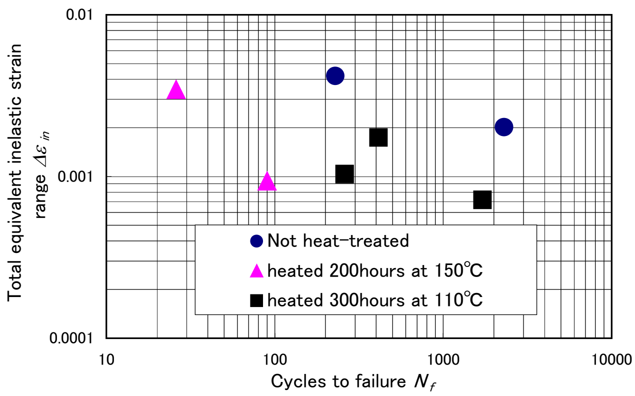

Fig. 6 S-N curves of Sn-8Zn-3Bi solder joints

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evaluated from the results of elasto-plastic analyses and the mechanical fatigue test. The results of fatigue life for the each lead free solder joint are shown in Figures 4, 5, 6, 7, 8 and 9.

Figure 4 shows that Sn-Cu-Ni solder joints have almost identical fatigue strength whether they were heat-treated or not. The fatigue failure mode was observed in details by the microscope to verify the above results. And it was observed that the crack initiated within the solder bulk (solder fatigue mode) for both cases.

Figure 5 shows that the results of the fatigue life of the heat-treated specimen of Sn-2.9Ag-0.5Cu-3Bi decreased a little in comparison with those of the specimen which was not heat-treated. It was shown that the fatigue cracks initiated within the matrix of solder material (solder fatigue mode) in the case of not heat-treated specimen. On the other hand, for the heat-treated specimen, the fatigue cracks initiated in the solder layer where is very close to the interface between the intermetallic compound layer and solder bulk, and they propagated with a path parallel to the interface (similar to an interface fatigue mode). This case was called solder/interface fatigue mode.

Figure 6 shows that the results of fatigue life of the not heat-treated Sn-8Zn-3Bi specimen were much longer than those of the specimen heat-treated by holding at 150ºC for 200 hours. It was observed that the cracks initiated in the solder bulk (solder fatigue mode) in the case of not heat-treated specimen, and the cracks in the specimen heat-treated by holding for 300 hours at 110ºC initiated and propagated with the similar mode of Sn-2.9-0.5Cu-3Bi solder joint. However, the fatigue cracks initiated from interface between the intermetallic compound layer and solder (a true interface fatigue mode) for the case of specimen heat-treated by holding for 200 hours at 150ºC. It was assumed that in this case there existed a reaction layer (CuSn) newly grown between the solder and intermetallic layer (ZnCu), and the cracks just started in this new layer.

The other type of fatigue test specimen used in this study is the BGA solder joints, where a dummy component was connected to a Cu-plated substrate by two lead-free solder balls. The lead-free solder materials used in these specimens are Sn-3.5Ag-0.75Cu and Sn-3.5Ag-5Bi. These specimens were heat treated by holding at 120ºC for 360 hours to grow the intermetallic layer, and the specimens are classified into four types as shown in Table 1.

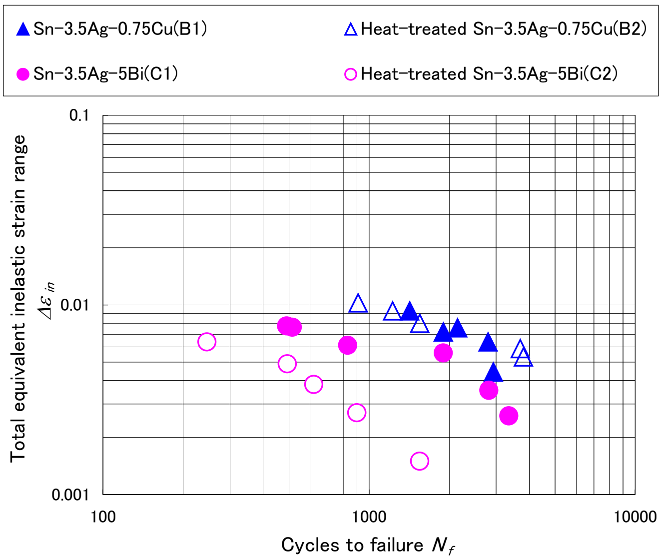
Figure 7 shows the results obtained by the mechanical fatigue tests and elasto-plastic analyses. The figure shows the following,

(1) the effect of heat treatment may be negligible in the case of Sn-3.5Ag-0.75Cu solder joints;

(2) the fatigue lives of the heat treated specimen of Sn-3.5Ag-5Bi(C2) decreased remarkably.

Table 1 Types of BGA specimens

	No heat treatment	Heat treated
Sn-3.5Ag-0.75Cu	B1	B2
Sn-3.5Ag-5Bi	C1	C2



Similar to Sn-Cu-Ni solder joints, the fatigue cracks in both kinds of BGA Sn-3.5Ag-0.75Cu joints (B1 and B2) started and propagated within the solder bulk layer. It means that since Sn-Ag-Cu solder joints broke with a solder fatigue mode, the fatigue life was not affected by the conditions of reaction interface between the solder and Cu pad. The situation was the same for the Sn-3.5Ag-5Bi specimen without heat treatment (C1), where the remarkable growth of the intermetallic compound layer could not be observed. On the other hand, the

Fig.7 S-N curve of BGA solder joints

interface in heat-treated Sn-3.5Ag-5Bi solder joints (C2), where the remarkable growth of intermetallic compound layer was observed, broke and the interface fracture mode resulted the great decease in the fatigue life.

YEILD STRESS AGAINST FATIGUE FOR IMC LAYER

As a result of the mechanical fatigue test, it was found that the fatigue failure mode of the solder joints depends upon the solder material and the condition of the reaction layer. To explain the reason the authors have noticed the nonlinear stress-strain characteristics of solder materials, which are shown in Fig.8.

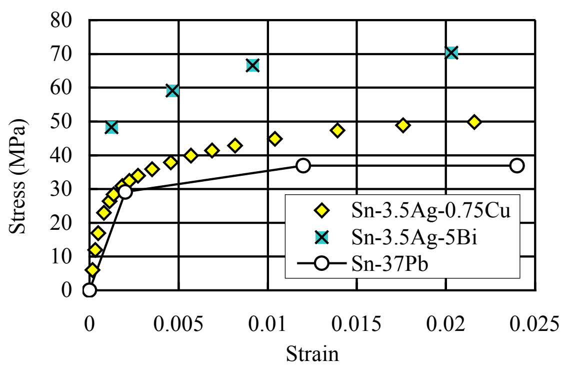


Fig.8 Stress-Strain curve of solder materials

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The figure shows that the flow stress of Sn-3.5Ag-5Bi is remarkably higher than those of Sn-Pb and Sn-3.5Ag-0.75Cu. It means that Sn-3.5Ag-0.75Cu like Sn-37Pb has a much lower yield stress to let the solder layer to deform easily as a cushion for hard and fragile intermetallic compound layer, so the stress applied on the interface layer can not increase high enough to break the reaction layer (intermetallic layer) during the fatigue test. However, lead-free materials with rich Bi are much harder than the Sn-Pb eutectic solder and more difficult to deform, and the higher yield stress may cause a very critical stress level on the interface layer. This may be the reason why a very fast fracture, which was close to a brittle fracture than a slow ductile fracture, occurred in and along the intermetallic compound. However, this kind brittle fracture just propagated with a very small scale in every cycle because the displacement controlled load could cause a stress relaxation quickly after the crack propagation. In the case of the specimen C2, because there existed the well-grown intermetallic compound layer due to the exposure at high temperature, and the high stress level due to the high yield stress of Sn-Ag-5Bi caused the brittle fracture at the intermetallic compound (interface fatigue mode), which resulted in the remarkable decrease of the fatigue life. It can assume that the same brittle fracture occurred also in Sn-8Zn-3Bi joints after 200 hours exposure at 150ºC, since the similar intermetallic compound layer to Sn-3.5Ag-5Bi joint existed at its interface. However, Sn-8Zn-3Bi could break only the interface of ZnCu intermetallic compound layer in the solder joint after 300 hours exposure at 110ºC. Because the toughness of ZnCu intermetallic compound is said to be higher than that of SnCu, this kind failure mode may not be a big problem.

The relation between tensile strength (flow strength at 2% strain) and fatigue fracture mode of each solder joint is shown in Table 2. It shows that the fatigue fracture mode shifts from the solder mode to the interface mode, as the solder hardens. From the above consideration, it is necessary to think about the stress concentration as well as the strain behavior when one wants to assess the thermal fatigue strength of the solder joints with remarkable intermetallic compound layers [6].

Table 2 Relation of fracture mode to tensile strength

Solder material	Tensile strength (MPa)	Failure mode
Sn-37Pb	38	Solder
Sn-Cu-Ni	35	Solder
Sn-3.5Ag-0.75Cu	49	Solder
Sn-Ag-0.5Cu-3.0Bi	58	Solder/Interface
Sn-8Zn-3Bi	66	Solder/Interface(110ºC) Interface(150ºC)
Sn-3.5Ag-5Bi	68	Interface

Figure 9 shows the distributions of Mises equivalent stresses at the interface layer in the solder joint of Sn-37Pb, Sn-3.5Ag-0.75Cu, and Sn-3.5Ag-5Bi, respectively. It shows that the stress concentration at the end of the interface in the Sn-37Pb solder joint is the lowest but that of the Sn-3.5Ag-5Bi is the highest. It is easy to know that the maximum stresses are

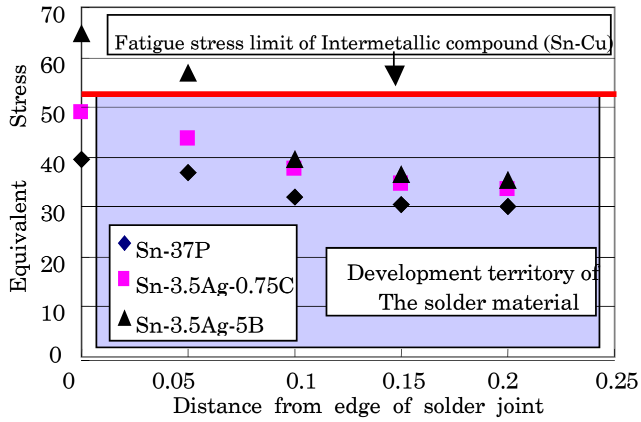

Fig.9 Distributions of Mises equivalent stresses

limited by the yield stresses of the solder materials, and it is impossible for the maximum stresses to increase over the yield stresses. The maximum stress of each kind of solder joint corresponds well to solder strength stress as shown in Table 2. This is because almost all stress components in solder domain are continuous to those in intermetallic layer at the interface, and the stresses arising in the solder domain are constrained by its nonlinear stress-strain relation. Therefore, there is not a singularity problem for the stress distribution for the plastic deformation case.

Based upon the above considerations and also from the results of the mechanical fatigue test, it can be assumed that there might exist a critical stress (or tensile strength of solder material) limit against interface fatigue fracture mode for each intermetallic compound SnCu and ZnCu. If the tensile strength of solder is lower than the limit, the fatigue cracks will appear within the solder bulk layer, that is the solder fatigue failure mode, and the fatigue life of this solder joints is dominated by Manson-Coffin's law of the bulk solder material. However, if the tensile strength is higher the limit, the brittle interface fatigue occurs much earlier than the solder fatigue life that is the interface fatigue mode.

Piecing up all of the above results, the critical stress limit for intermetallic SnCu should be drawn some where in between the maximum stresses of Sn-3.5Ag-0.75Cu and Sn-3.5Ag-5Bi as shown in Fig. 9, or be exact, the critical stress is close to the tensile strength of Sn-2.9Ag-0.5Cu-3Bi, 58MPa, because it has been checked that the major failure mode of this solder joints was something like a mixed mode of solder and interface modes (solder/interface mode). It means the failure mode of Sn-2.9Ag-0.5Cu-3Bi joints located just at the borderline of the two major failure modes. In the case of Sn-3.5Ag-0.75Cu, most of the cracks initiated within the solder layer, since its tensile strength limits the maximum equivalent stress concentration at the end of the solder joint not to cross over the critical stress. For the same reason, it was very rare to find an interface fatigue failure mode in the Sn-Pb solder joints.

On the other hand, in the case of Sn-3.5Ag-5Bi, the tensile strength is higher than the critical stress, and as a result the brittle fracture at the intermetallic compound caused a great decrease in the fatigue life. Based upon the results shown in

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Fig. 6 and Table 2, it can be assumed that the limit stress for ZnCu is roughly between 60 to 68 MPa.

The above consideration shows that the reliability engineers have to think of the balance of the strengths of both of the intermetallic compound and the solder matrix if they want to design the fatigue reliability of a lead-free solder joint. In order to avoid the brittle fracture at the intermetallic compound layer, they have to consider the flow characteristics of the lead-free material, or they have to manage to prevent the growth of the intermetallic compound by the plating materials.

EFFECT OF VOIDS ON THERMAL FATIGUE RELIABILITY OF LEAD-FREE SOLDER JOINTS

In the mechanical fatigue test, it was found that the thermal fatigue strength of lead-free solder joints is almost equivalent to that of Sn-37Pb eutectic solder joints. However, there is the serious problem that voids are easily formed in the lead-free solder joints during the reflow process, and the effect of the void formation on fatigue strength of solder joints has attracted attention. Therefore, to investigate the effect of the voids on the fatigue life of solder joints, the authors carried out isothermal mechanical fatigue test of the CSP Pb-free solder joints, and calculated the equivalent plastic strain of solder joints with voids using FEM analysis. Finite element analysis code ANSYS was used for analysis.

The solder material of the specimens is Sn-3Ag-0.5Cu. Many voids were formed in solder joints by changing temperature condition during reflow. Figure 10 shows X-ray images that were taken from a top view and a bird's-eye view. The position and size of voids can be confirmed by X-ray images in advance. And, before the mechanical fatigue test, solder bump of first row were cut at the center section for observation of crack propagation. The mechanical fatigue test was carried out with the displacement control mode and enforced displacement was given as a triangular wave of 0.2Hz. Solder joint was observed with a microscope throughout the test, and displacement given directly to the solder bump, that is, relative displacement $\Delta\delta_{re}$ and the length of the figure the crack were measured.

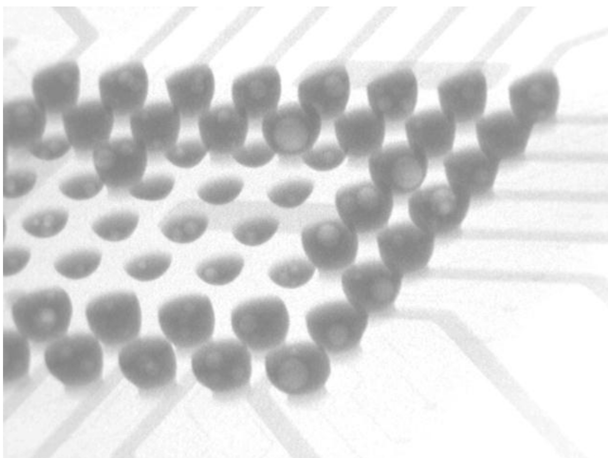


Fig.10 X-ray images of solder joint

Figures 11 shows images of solder joint without void before and after mechanical fatigue test. In CSP specimens, the lower land diameter (ϕ 300μm) of the solder joints is larger than the upper land diameter (ϕ 240μm). Therefore, the crack is easy to propagate on upper area. Three specimens were examined. The number of cycles was defined as fatigue cycle when solder breaks completely. Eight solder joints were observed in each specimen.

(a) Image of solder joint without void before test

(b)Image of solder joint without void after test

Fig.11 Images of solder joint without voidbefore and after test

Figure 12 shows the relationship between fatigue lives of solder joints and the position and size of the void in each specimen. Figure 13 shows that the fatigue life of solder bump tends to decrease by growing of void when void is generated on the chip side, where the fatigue crack propagated. When ϕ 80 μm void is formed on crack propagation route of solder joints, the fatigue life decrease about 30% from the fatigue life of solder joints without voids. However, when ϕ 120μm void was formed on substrate side, where is away from the crack propagation route, the fatigue life of solder joint didn't decrease from of the solder joints without voids.

Figures 13 show solder joints images of lead-free specimen after mechanical fatigue test. A ϕ 140μm void was formed in both solder joints. And the fatigue life of solder joint without void is about 1600 cycles. As shown in Figure 6-(a), when the void was formed on crack propagation route, the fatigue life of solder joint is about 1100 cycles and decrease by about 32% from 1600 cycles. However, as shown in Figure 6-(b), when void was formed on substrate side, away from the crack propagation route, the fatigue life of solder joint is about 1650 cycles and is almost equal to that of solder bump without void.

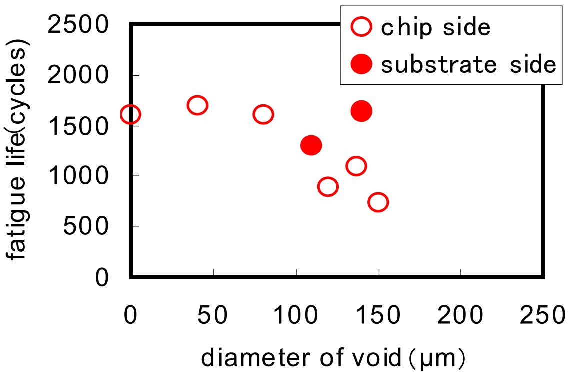
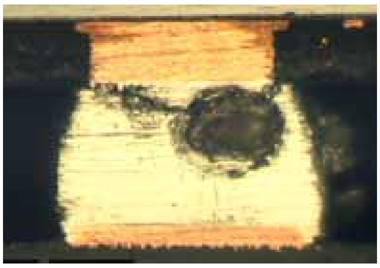
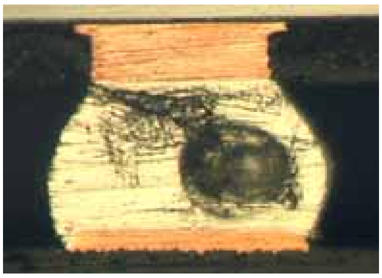


Fig.12 the relationship between fatigue life of solder joints and the position and size of the void in solder joints



(a) solder joint with void formed on crack propagation route (void's ϕ 140μm fatigue life: 1100cycles)



(b) solder joint with void formed away from crack propagation route (void's ϕ 140μm fatigue life: 1650cycles)

Fig.13 Solder joints images after mechanical fatigue test

Based on the results, it was confirmed that formation of void doesn't necessarily have a bad influence on the fatigue life of solder joint and that is influenced by the position and the size of voids. When the diameter of a void is under 1/3 of upper land diameter, the effect on the fatigue life can be ignored. And, when a void is formed away from the crack propagation route, the formation of voids does not have great effect on the fatigue life of solder joints. Therefore, when the diameter of a void is over 1/3 of the diameter of solder bump, there is very high risk to decrease the fatigue life of the joints.

CONCLUSION

In this study, the effect of material property of lead-free solder on the reliability of solder joints was clarified. It was found that there exist two kinds of major fatigue failure modes; one was the solder fatigue mode, and the other was the interface fatigue mode. The interface fatigue mode results greatly decrease the fatigue life of solder joints. Furthermore, the mode transition from solder to interface is not only affected by the conditions of the reaction layer but also greatly controlled by the tensile strength of the solder material. The fatigue strength of 95.75Sn-3.5Ag-0.75Cu, Sn-Cu-Ni, Sn-2.9Ag-0.5Cu-3Bi lead free solder joints are not greatly affected by intermetallic compounds formed during thermal cycles as the Sn-Pb solder, because their tensile strengths are lower than a critical limit, and the fatigue fracture is dominated by the solder fatigue mode. However, in the case in which solder material contains much Bi (over 5%), the crack initiates easily along the interface between intermetallic compound layer and solder material. This is because the high-level tensile strength of Sn-3.5Ag-5Bi lead free solder causes severe stress distribution in the interface. Based upon the given results, the possibility of giving guidelines for the new solder material development was suggested by showing the limit stress of fatigue strength of Sn-Cu intermetallic compound. And it seems to be able to obtain a limit stress for the intermetallic compound of Zn-Cu, as well as Sn-Cu.

The effect of voids on fatigue life of lead free solder joints was examined using isothermal mechanical fatigue test. Based on the results, it was confirmed that formation of void doesn't necessarily have a bad influence on the fatigue life of solder joint and that is influenced by the position and the size of voids. When the diameter of a void is under 1/3 of upper land diameter, the effect on the fatigue life can be ignored. And, when a void is formed away from the crack propagation route, the formation of voids does not have great effect on the fatigue life of solder joints. Nevertheless, when the diameter of a void is over 1/3 of the diameter of solder bump, there is very high risk to decrease the fatigue life of the joints.

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