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Controlling technology of Sn whisker in welding of electronics lead

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ABSTRACT

This paper describes development for preventive technology of Sn whisker in welding of aluminum electrolytic condenser lead. Sn whisker is the crystal of tin and the length of Sn whisker is from several μm to several mm. Sn whisker has been causes for failure in electric device occasionally. The lead of aluminum electrolytic condense is composed of Sn and Cu plated Fe wire (named CP wire) and Al wire by Percussion welding. From observation, Sn whisker occurred from Al-Sn alloy area in welding point. We considered exclusion Sn from welding point. In this experiment, we used Sn plated-less CP wire with mold in welding. This mold is addition to chucking unit of welding machine. We obtained good shape and sufficient bonding strength by this method. There is no Sn whisker on the welding point after accelerated test during 4000hr.

Keywords: Sn whisker; Percussion welding; CP wire; Tensile strength; Sn plated; Mold welding; Lead welding

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1. Introduction

The aluminum electrolytic capacitor is widely used in various devices, for example, household electrical appliances, information communications equipment, industrial apparatuses, and automobiles. It consists of a steel wire and an aluminum line with Sn plating as part of the lead, which are butt-welded.

Fig. 1 shows the weld zone of an aluminum electrolytic capacitor section used in this research. Recently, in the lead of the aluminum electrolytic capacitor, Sn whiskers have been shown to easily grow in Pb-free weld zones. Fig. 2 shows a Sn whisker grown in the weld zone of the lead of an aluminum electrolytic capacitor. This Sn whisker is a Sn crystal in the shape of a mustache with a length on the micrometer to millimeter order. When this Sn whisker falls off, there is concern that a short circuit will occur, posing problems in electronic equipment. Thus, in this research, we developed techniques for preventing Sn whiskers in the percussion welding of the lead of the aluminum electrolytic capacitor.

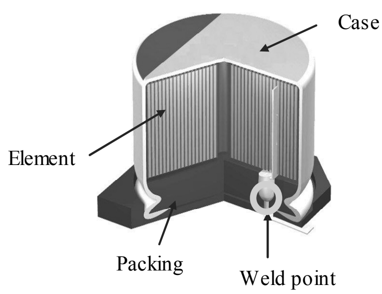

Fig. 1. Detail section structure of aluminum electrolytic condenser and weld point

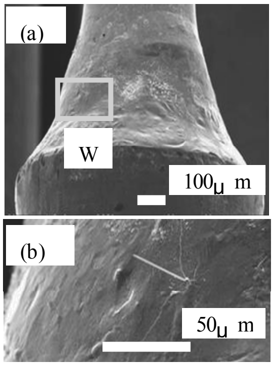

Fig. 2. Whisker at weld point a) weld point, b) detail observation of box region of W

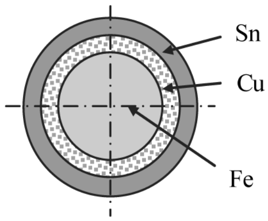

Fig. 3. Schematic structure of Sn and Cu plated Fe wire (named CP wire) structure for aluminum electrolytic condenser

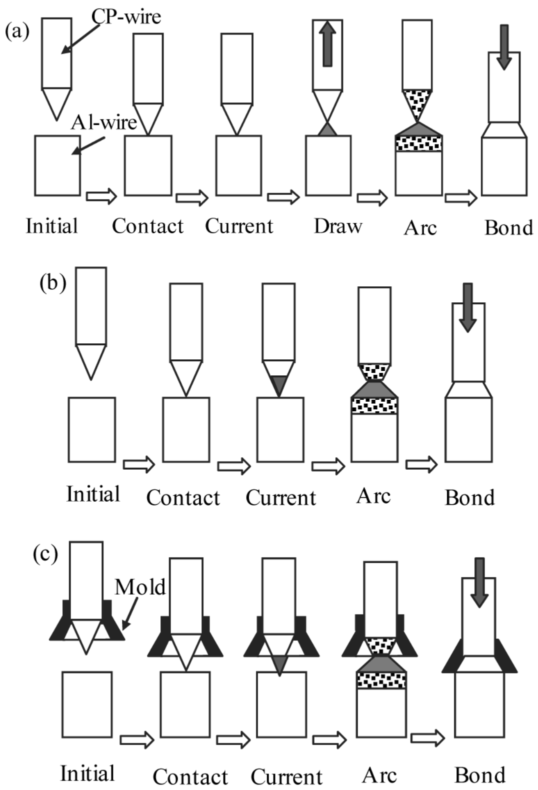

Fig. 4. Percussion welding process with Al-wire and CP-wire

2. Experimental sample and method

The lead of the aluminum electrolytic capacitor comprises the weld zone of a CP line and a tab.

Fig. 3 shows the structure of the CP line. The CP line is a soft steel wire with Cu plating and Sn plating; it has a diameter φ of 0.45 mm. The tab is made of 99.9% Al and has a diameter φ of 0.85 mm. Fig. 4 shows a basic welding process [3], (a) Two materials are placed in contact with each other, generating electricity; an arc then occurs when the materials separate, (b) Two materials are placed in contact with each other, generating electricity; by venting the leader of the CP line, an arc occurs. As for the movement involved in the process, (a) is a reciprocating motion and (b) is a single motion. Therefore, an arc forms when (b) is shorter. Method (b) is used in this research. Method (c) is used to denote the method devised in this study; it adds a molding function to the weld zone. Fig. 5 shows the welding equipment used in this research.

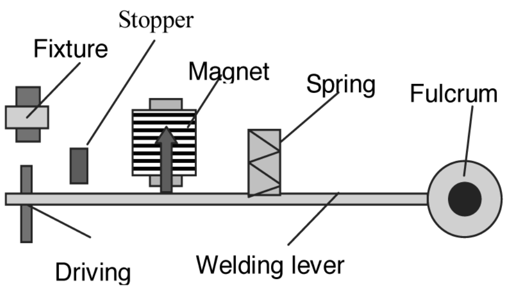

Fig. 5. Welding unit

3. Experimental results and consideration

3.1. Internal structure of weld zone

Fig. 6 shows the elemental distribution of the weld zone. All the elements, namely, Al, Cu, Fe and Sn are welded. The CP line side of the terminal part of the welding is made of Sn and Al, it follows a smooth curve. Because the Sn whisker grows from a domain at which Al and Sn mix, Sn exclusion from a weld zone prevents Sn whisker growth [1,2].

3.2. Effect of weld zone on Sn plating

Fig. 7 shows the shape of the CP line with Sn plating. Molten metal forms a smooth curved surface. Fig. 8 shows the shape of the CP line without Sn plating. When the welding voltage is greater than 77 V, the molten metal opens outward from the diameter of the tab. Fig. 9 shows the elemental distribution of the weld zone at 77 V. The molten metal mainly composed of Al solidifies toward the outside. In this case, because there is no Sn, the wettability of molten Al for the CP line is poor, owing to the effect of the surface tension of the molten Al. The lead is inserted in the hole of a rubber packing as in Fig. 10 in the manufacturing process. The protruding shape of the CP line without Sn is an obstacle in fabrication. Fig. 11 shows the result of the test of tensile strength. A small difference in axial tensile strength is observed between the cases with and without Sn plating. On the other hand, a large difference in vertical tensile strength was observed, which indicated the need for Sn plating. Therefore, the vertical tensile strengths are significantly different. Thus, structural factors are also estimated.

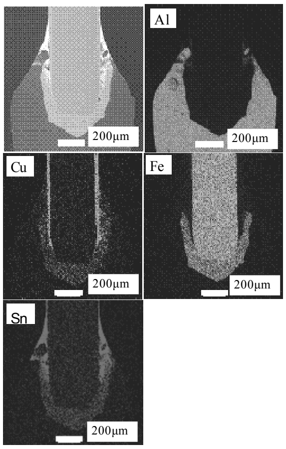

Fig. 6. Cross-sectional EDS analysis ofthe weld with Sn plated CP wire

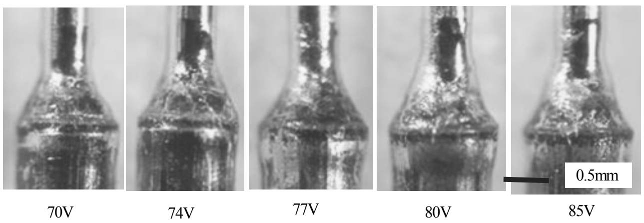

Fig. 7. Change of normal welding shape by welding voltage

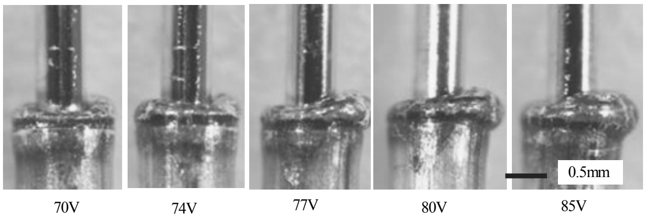

Fig. 8. Change of Sn-less welding shape by welding voltage

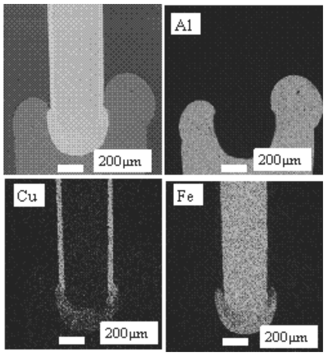

Fig. 9. Cross-sectional EDS analysis of the weld with Sn -less CP wire

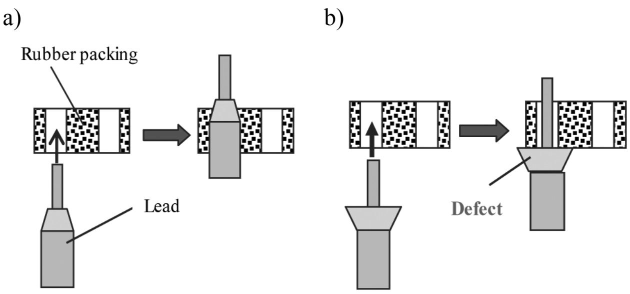

Fig. 10. Effect of welding shape on packing process, a) Normal welded lead, b) Sn-less welded lead

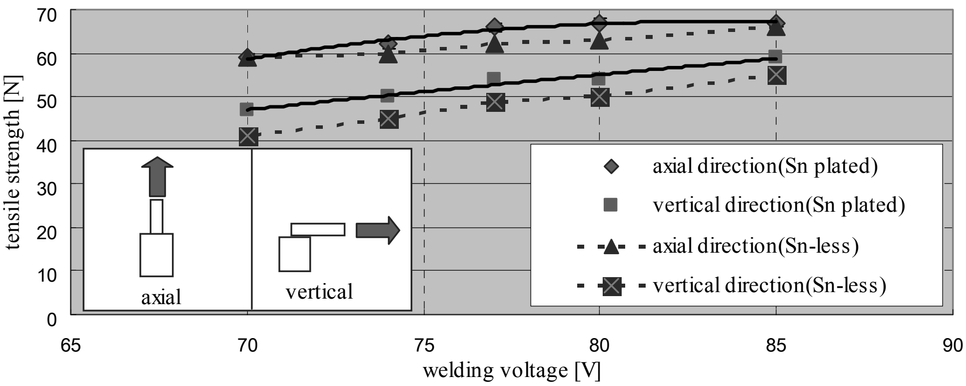

Fig. 11. Tensile strength by welding voltage

3.3. Relations of welding strength and connection structure

Figs. 12 and 13 show X-ray images of the weld zones, that is, the CP line with Sn plating and the CP line without Sn plating, respectively. The insertion depth is shallower in the case with Sn plating than in the case without it. Fig. 14 shows the relationship of the insertion depth of the CP line with or without Sn plating and vertical tensile strength. In both cases with and without Sn plating, vertical tensile strengthis proportional to the insertion depth of the CP line. This insertion depth is a structural factor. Fig. 15 shows an SEM image of the fracture surface from the strength examination of the CP line without Sn plating as well as the result of the ultimate tensile strength analysis. Because Al is detected on the fracture surface, this side is understood that fracture did not occur at the interface between the CP line and tab [4].

3.4. Molding processing of weld zone with mold

The problem with the CP line without Sn plating concerns the shape of the weld zone. In this research, we solidify a weld zone in a mold using a CP line without Sn plating and mold it. We call this process Sn-free molding welding. Because the fluidity of the materials is high, the processing load is low and the filling characteristics are excellent. When a CP line in the mold melts, molten metal flows into a mold. Because joining and molding are carried out at the same time, a stable welding shape can be realized with simple welding equipment.

The opening of the mold has a diameter of 1.05 mm, considering here the movement precision during mass production. Thus, the quantity of molten metal should be constant to achieve a stable welding shape. The result of this research indicates that it is necessary to control the duration of the arc within a range of 1.5 ± 0.1 ms. In addition, the durability of a mold should be verified in mass production because an impact load is repeated applied.

3.5. Effect of mold form

Fig. 16 shows the appearance at each welding voltage of a forming metal mold with a depth of 0.3 mm. The mold form is transferred and the weld zone becomes hemispherical. At a voltage less than 74 V, a dent forms near the CP wire base of the weld zone. At 77 V, the amount of molten metal becomes sufficient and the metal mold form is transcribed. At a voltage greater than 80 V, a boundary between the tab and weld zone (hereinafter referred to as the weld zone boundary) is formed in the projection. Leakage from the clearance of the forming processing metallic mold of a molten metal and a tab indicates poor quality. At 85 V, a projection becomes ringlike in a welding boundary part. Fig. 17 shows the appearance at each welding voltage of a forming metal mold with a depth of 0.6 mm. At a voltage greater than 80 V, the leakage of molten metal from the boundary portion of the weld zone indicates poor quality. Even if voltage increases to 95 V, as shown in Fig. 18, the length of a weld zone is constant at 0.4 mm. The metal mold depth is 0.6 mm with a 0.2 mm space. When solidification ends, the projection becomes larger. Because a welding trailer precedes the solidification of molten metal, it is thought that molten metal is pushed out of clearance. Since a filling factor is governed by the above-mentioned clearance, there is a limit. It is thought that the solidification caused by a high filling factor is effective in welding end-like stabilization. Here and elsewhere. It is thought that the solidification caused by a high filling factor is effective in welding endlike stabilization. From the result of this research, a good form can be achieved if the metal mold depth is 0.3 mm, the diameter of the opening is 1.05 mm, and the welding voltage is 77V.

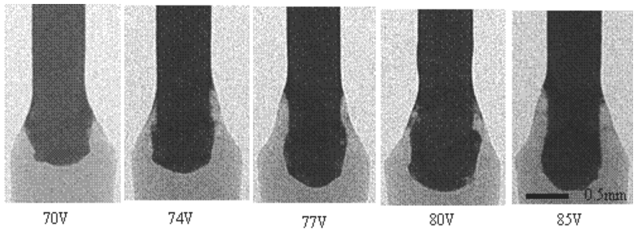

Fig. 12. X-ray photograph of normal welding by welding voltage

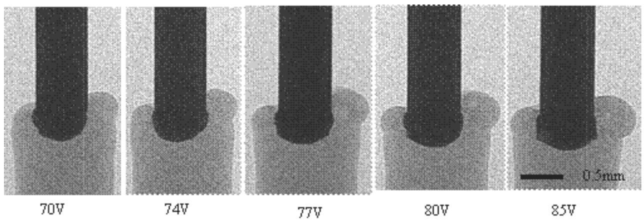

Fig. 13. X-ray photograph of Sn-less welding by welding voltage

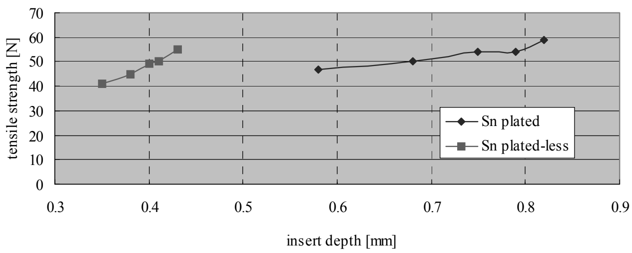

Fig. 14. Tensile strength of vertical direction by insert depth

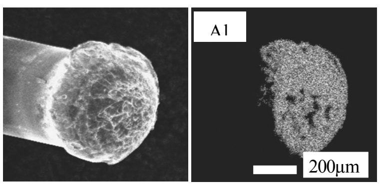

Fig. 15. EDS analysis of CP wire after tensile test with Sn -less CP wire

3.6. Evaluation of a connection state

Connection quality in welding was evaluated with a metal mold with a depth of 0.3 mm. Fig. 19 shows the welding intensities at all welding voltages. Although the change in the direction tension strength of an axis is small, perpendicular tensile strength intensity clearly shows an upward tendency. At a voltage greater than 77 V, the intensity is equivalent to that of the CP wire with Sn plating in the domain. Intensity increases by about 20% compared with that in the case when no metal mold is used. Fig. 20 shows the elemental distribution of the weld zone at a welding voltage of 77 V. The molten metal consists of aluminum. Since there is no Sn plating in the CP wire at the edge of the weld zone, it gets wet owing to the Cu plating of melting aluminum and the low wettability. Therefore, although the boundary with the CP line is not gently sloping, the molten metal is brought near the central part by the metal mold. The molten material in the CP wire with Fe and Cu platings is the same as that for the CP wire with Sn plating. When not using a forming metal mold, the welding voltage (85 V), which gives perpendicular tension strength, of the CP wire without Sn plating becomes equivalent to that of the CP wire with Sn plating, but it can decrease to 77 V with the use of a forming metal mold.

Welding intensity increases with improvement in the reinforcement effect in the CP wire base. Moreover, the obstacle during rubber packing insertion posed by the projection of the weld zone in the CP wire with no Sn plating is cancelled by the use of a forming metal mold.

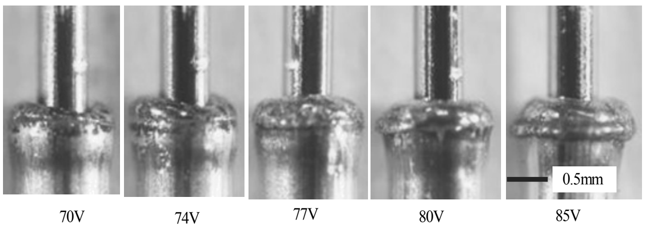

Fig. 16. Change of Sn-less mold welding shape by welding voltage with mold depth 0.3 mm

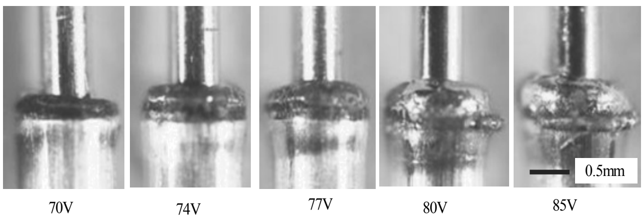

Fig. 17. Change of Sn-less mold welding shape by welding voltage with mold depth 0.6 mm

Fig. 21 shows the X ray for every voltage of Sn-free fabrication welding. With an increase in welding voltage, the amount of molten metal increases as well as insertion depth. At 85 V, molten metal overflows the clearance part of the forming metal mold, jutting out as a ringlike projection on the perimeter of weld.

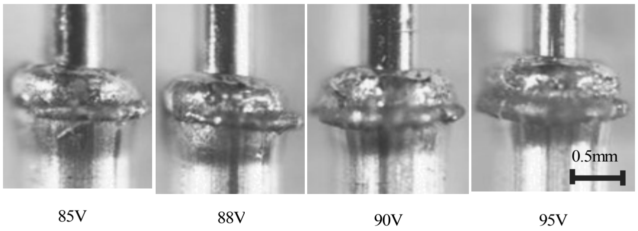

Fig. 18. Sn-less mold welding shape by welding voltage with mold d NG condition

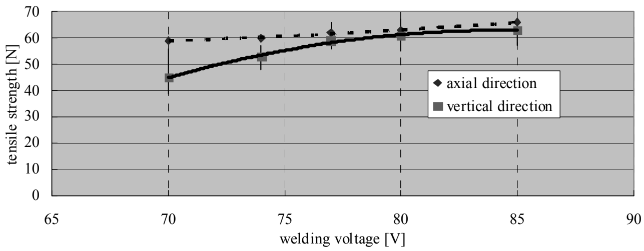

Fig. 19. Tensile strength of Sn-less mold welding by welding voltage

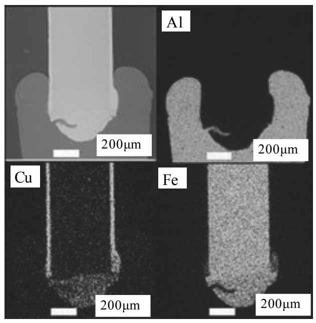

Fig. 20. Cross-sectional EDS analysis of the weld with Sn-less CP wire by mold

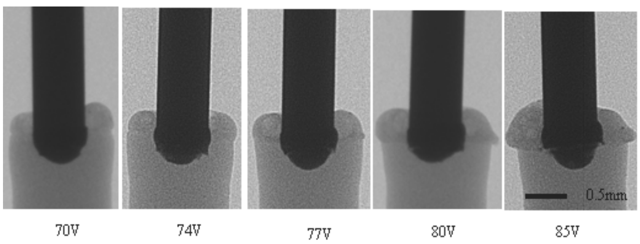

Fig. 21. X-ray photograph of Sn-less mold welding by welding voltage

Fig. 22 shows a comparison of the insertion depths with the case of the forming metal mold. Since molten metal is brought near the central part when using a forming metal mold, the insertion depth increases. To stabilize inner welding intensity in Sn-free assembly welding, an insertion depth of the CP wire of 0.45 mm or more is sufficient.

Insertion depth in this case consists of two kinds of modification elements of the adhesion length of the insertion depth to a tab and the swelling of molten metal contacted with CP wire, as shown in Fig. 23.

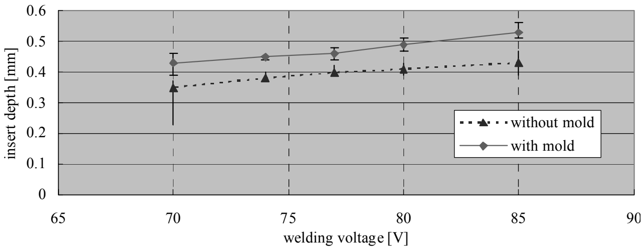

Fig. 22. Insert depth of Sn-less welding by welding voltage

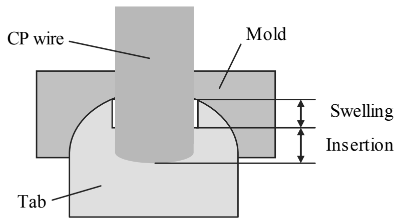

Fig. 23. CP wire supported by swellingvand insertion parts

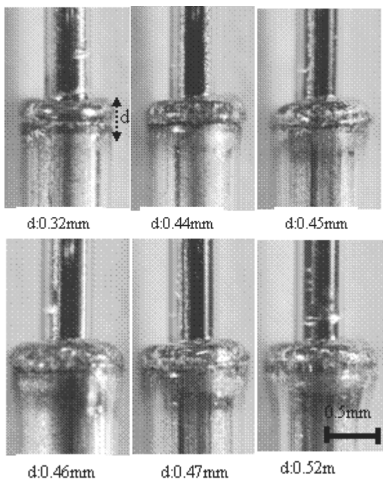

Fig. 24. Change of Sn-less mold welding shape by insert depth(d) at 77V

The intrusion depth for a tab is controlled by changing the position of the stopper of a welding lever. Fig. 24 shows the welding appearance at a welding voltage of 77V with varying insertion depth of the CP wire. The diameter of the tab near the weld zone increases with an increase in the volume of the CP wire accompanying the increase in insertion depth. This increase in tab diameter may be smaller that required for convenience of sealing aluminum electrolytic capacitors. Fig. 25 shows the relationships between insertion depth, tab diameter, and intensity. The immersion depth, which was obtained at sufficient weld strength, is about 0.45 mm, and the rate of tab diameter increase at this depth is about 5%. Thus, it is effective to reduce the opening size of a forming metal mold, in order to reduce the rate of tab diameter increase, and to set the insertion depth in an appropriate range.

3.7. Circumference technology of Sn-free fabrication welding

There are two methods of preparing a domain with no Sn plating in the weld zone of the CP wire. One is the deletion of the Sn plating of only the weld zone of the CP wire. The other is installing Sn plating on the Cu plating portion of the CP wire after welding using a CP wire without Sn plating.

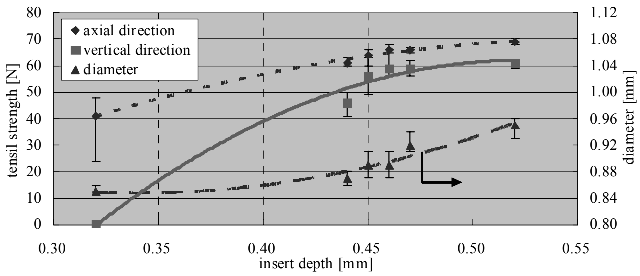

Fig. 25. Tensile strength and diameter of Sn-less mold welding by insert depth

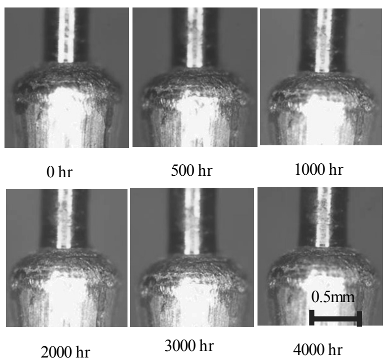

Fig. 26. Whisker accelerated test on 55°C, 85%

3.8. Sn whisker evaluation of a weld zone

To evaluate Sn whisker generation, a Sn whisker was left to stand under 55°C/85% RH for 4000 h in an accelerated test. Similarly, a Sn whisker for the evaluation of the incidence was left to stand under the same conditions for 4000 h. The weld zone was observed every 1000 h, and Sn whisker generation and the variation in the appearance of the weld zone were observed every hour. As shown in Fig. 26, no Sn whiskers were generated from the weld zone after 4000 h, and the weld zone showed no change in appearance.

4. Conclusions

The following results were obtained in this research:

1. By providing a mold to form a chuck portion of a CP wire in the percussion welding of a lead wire, and molded in a molten state, control of the weld shape of CP wires with no Sn plating can be achieved and the outward spread of the weld zone spread can be prevented. This welding system is called Sn-free fabrication welding.
2. It is thought that, by eliminating Sn, which serves as the source of Sn whiskers, by Sn-free fabrication welding, complete prevention of Sn whisker formation from a weld zone is possible in the fabrication of aluminum electrolytic capacitor.
3. The weld zone produced by Sn-free fabrication welding usually has sufficient connection strength as well as a good appearance.
4. When a depth of 0.3 mm and an opening size of 1.05 mm in diameter of the hemispherical forming metal mold are used in Sn-less fabrication welding of CP wire with a diameter of 0.45 mm, at a welding voltage 77 V, the filling factor inside a metal mold is about 100%, and the shape of a welding end is stabilized.

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