Importance of Wave Height Control in Wave Soldering

HIROSAKI Akihiro, TAMURA Toshiyuki and UENO Yuji

Not only high-function electronic products such as PCs and smartphones but also the products such as FA equipment and power electronics products have being downsized. The heat capacity of the printed wiring board (PWB) is increasing due to multi-layering of the PWB and increase in its thickness. Wave soldering with high heating performance is often used for soldering large components, but sufficient heating is becoming difficult due to high heat capacity of boards and components. In order to realize the wave soldering process that can cope with the increase in the heat capacity of the board, it is necessary to improve the solder wave control. However, it is difficult for young production engineers to understand the importance of the wave control because they have few opportunities to gain experience in the production line. Therefore, from the viewpoint of heat supply, we focused on solder wave and evaluated the change in soldering state due to fluctuation of the solder wave shape. Stabilizing the wave shape depends on the skill of the engineers. In this paper, we clarify the importance of wave height control to stabilize soldering quality by showing the relationship between the wave height, which is one of typical values of the wave shape, and the temperature of board and component terminal. We also clarify the necessity of wave control and show that finer control is needed to cope with high heat capacity boards.

1. Introduction

Miniaturization of electronic products, such as FA equipment and power electronics, handling large electric current in addition to the intelligent electronic products, such as PCs and smartphones, is a trend. The heat capacity of the printed wiring board (PWB) is increasing because of multi-layering of the PWB, increase of the copper foil thickness, and associated increase of PWB thickness to meet such miniaturization requirements of the products handling large electric current. The heat capacity of the parts mounted on the PWB for such products also increases, such as the free-standing large aluminum electrolytic capacitor[1]. As it takes time to solder the parts with high heat capacity because rate of temperature increase becomes slow[2], wave soldering with high heating capacity is commonly used, but even when wave soldering is used, it becomes difficult to meet the heating requirements of the recent PWB with high heat capacity. If the heating applied is inadequate, it is impossible to fill the through hole with solder and strength of the solder joint can decrease.

Solder and heat are supplied by melted solder to the PWB in wave soldering, and the quality of the solder joints is dependent on the condition of waving. While in the manufacturing process, the condition of waving is controlled within a certain range based on the process control standards, it is difficult to control the constantly changing waving condition within the acceptable range, unless the production engineer understands the condition of good waving and why such condition is a good condition. The experienced engineer had acquired the skill to determine the good wave soldering condition based on experience, but junior engineers in recent years lack the opportunity of acquiring such experience and have only basic and superficial knowledge. Precise control of the wave soldering condition is required for difficult soldering of the PWB with high heat capacity, which requires improved skills of the engineer controlling the process because it is difficult to measure the wave shape quantitatively in the production line. The authors considered that providing the data showing the effect of wave shape change to the quality of soldering can make up for inadequate experience on the production line. In this paper, the relationship between the wave height and the temperature of the PWB and parts terminals, which is one of the factors determining the wave shape, is evaluated from the perspective of heat supply, and the importance of the wave height control to stabilize quality of soldering is clarified.

Even when the required heat can be supplied, if the amount of flux is not sufficient, wettability of the solder decreases, and it adversely affects the quality of the soldering. This paper shows the problems due to overage/shortage of the flux under adequate heating condition.

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2. Issues involved in Stabilizing the Wave Process

Schematics of the wave soldering process are shown in Fig. 1[3]. The process consists of the flux spraying and wave soldering, and by the wave soldering system, heating is provided in three steps: preheating, 1st wave, and 2nd wave, respectively. In the preheating step, vaporization of the solvent contained in the applied flux and preheating of the PWB take place. Wave shapes used are two types, the first wave where solder blows up in many positions to form a small mountain shape, and the second wave where solder gently flows forming one lump. The first wave is intended to effectively supply solder into the through hole and to the joints of the concentrated surface mounted parts, and the second wave is intended to make a good fillet shape. In wave soldering, the supply condition of the heat and solder by the wave is the critical factor in determining the quality of soldering, but as the wave condition is easily affected by the condition of the equipment and fluctuation of the condition of the melted solder, the wave condition is also a factor most likely to fluctuate. The authors considered stabilizing the heat supply by the wave will be increasingly important because the heat required for soldering increases with the increase of heat capacity of the PWB, and decided to use flow-up (the condition the through hole is filled with solder to the level of upper surface) as an item of the evaluation and show the relationship between the fluctuation of the wave and the soldering condition.

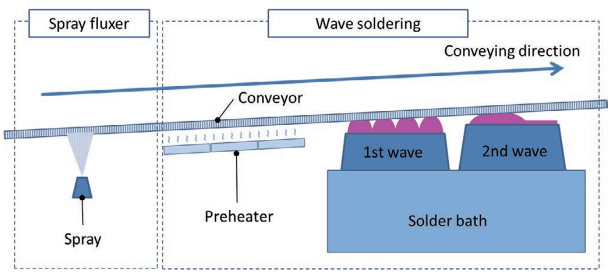


Fig. 1 Schematic of the Wave Soldering Process[3]

In addition to the aspect of heat supply, the relationship between the amount of flux applied and soldering condition was evaluated because the reduction action is required for the flow-up. When the amount of flux applied is not sufficient, the wettability of solder decreases, and when it is excessive, the reliability risk will increase due to generation of voids, although good wettability can be obtained.

3. Details of the Experiment

3.1 Outline

Three experiments were conducted to confirm how the soldering condition changes due to changes in the wave and flux. First, the temperature required for flow-up was checked. Evaluation of the flow-up by a temperature measurement became possible by linking the temperature of the PWB and parts with the flow-up. Next, temperature changes caused by change of the wave were evaluated, and the importance of wave control was confirmed. And in the last experiment, the soldering condition was evaluated with the amount of flux applied changed. Composition of the solder used in the experiment was Sn 96.5/ Ag 3.0/Cu 0.5 (wt. %).

3.2 Experiment to confirm flow-up temperature

Temperature of the base metal needs to be increased above the melting point of the solder because an alloy layer must be formed between the solder and the base metal. In order to know the flow-up to the upper face of the PWB, points on the upper face of the PWB were selected as the temperature measurement points (Fig. 2). The temperature of the base metal when the solder flows up to the temperature measurement point is the temperature required for flow-up. Whether the flow-up occurred is determined by the temperature profile. As the temperature measured by the thermocouple attached on the temperature measurement point jumps up when it contacts the melted solder, the flow-up temperature is determined as the temperature just before the temperature jumps up. To ensure flow-up, the solder temperature was set to 270°C, and heat was applied for 10 seconds with the conveyer stopped in the middle of a wave.

Table 1 shows specification of the PWB used for evaluation. A large free-standing large electrolytic was used as the mounting part. Measurement using the two-layer evaluation PWB with the same pattern dimension was made to confirm that the flow-up temperature obtained also applies to the PWB other than the evaluation PWB used.

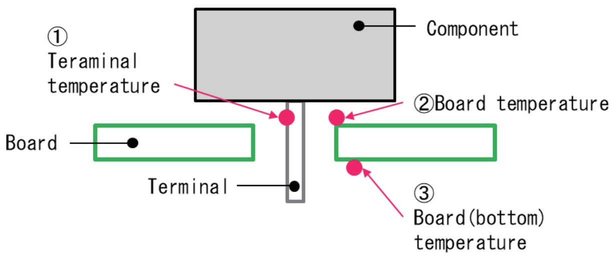


Fig. 2 Temperature Measurement Point

Table 1 Specification of Evaluation PWB

External size	50 mm×50 mm×1.6 mm
Cu pattern size	45 mm×45 mm×0.035 mm
Number of layers	6 and 2
Through hole diameter	2.0mm

3.3 Experiment to evaluate wave height

On the production line, contact between the wave and the PWB is checked by the glass panel or temperature measurement. No special skill is required to simply determine whether contact occurred, but experience is required to determine to what extent the heating performance is different and whether the quality of soldering is acceptable. The relationship was evaluated between the conditions of the wave height that is believed to significantly affect heat supplied to the PWB and temperature.

Table 2 shows the conditions of evaluation. Wave height is defined using the PWB as the reference. As shown in Fig. 3, the maximum wave height where the solder does not go up on the PWB when the PWB enters the solder wave is defined as the PWB upper limit, and the wave height that is 1.5 mm lower (≈ thickness of the PWB) than the upper limit is defined as the PWB lower limit. Adjustment of the wave height between the upper limit and lower limit is made by raising or lowering the solder bath. The 1st wave and 2nd wave were evaluated, and soldering times of the 1st and 2nd wave were about 2.5 seconds and about 2.1 seconds, respectively, when the conveyor speed was 1.0 m/min.

Table 2 Conditions for Evaluation of Wave Height

Wave height	PWB upper limit/PWB lower limit
Solder temperature	260°C
Conveyor speed	1.0m/min
PWB	Six-layer evaluation PWB

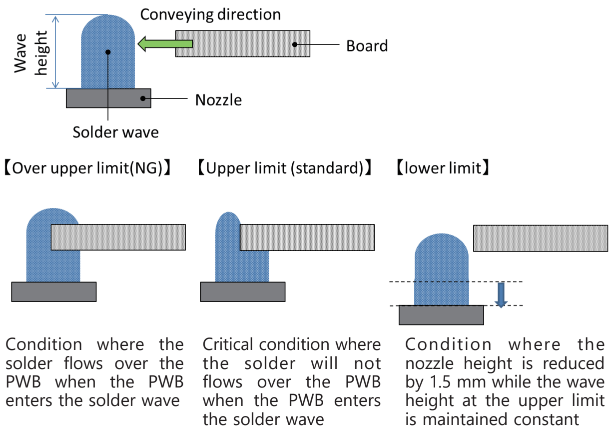


Fig. 3 Definition of Wave Height

3.4 Experiment to evaluate amount of flux applied

In addition to the base metal, temperature removal of the oxide film from the base metal by the flux is required so that the flow-up can occur. Even when the temperature of the base metal is the temperature suitable for soldering, wetting by solder does not occur, and a proper solder joint is not formed if oxide film is present. Accordingly, the amount of flux applied and whether the flux is uniformly applied are checked on the production line. In the experiment, the effect of the amount of flux applied on the soldering condition was evaluated for three degrees of application: too small, appropriate amount, and excessive. Conditions of flux application are shown in Table 3.

Table 3 Evaluation Condition of Flux

Amount of flux applied (a) Too small, (b) Appropriate, (c) Excessive	(a) 30 ml/m^2, (b) 100 ml/m^2, (c) 100 ml/m^2+brush coat
Conveyor speed	1.0 m/min
Nozzle speed	600 mm/s

4. Results of Experiments

4.1 Results of experiment to confirm flow-up temperature

Fig. 4 shows the temperature profile measured. The temperature of both the PWB and the terminal jumped up at about 180°C. The temperature where it jumps up is the same when two-layer PWB with lower heat capacity was used. So, it was decided to continue the evaluation assuming 180°C as the flow-up temperature. The reason why the flow-up temperature is lower than the solid phase point 217°C of Sn/Ag 3.0/Cu 0.5 solder[4] is because the temperature measured is not the temperature of the base metal but the temperature of the thermocouple. While the thermocouple is in contact with the base metal but also with the air, it indicates a temperature lower than the base metal as the measured value.

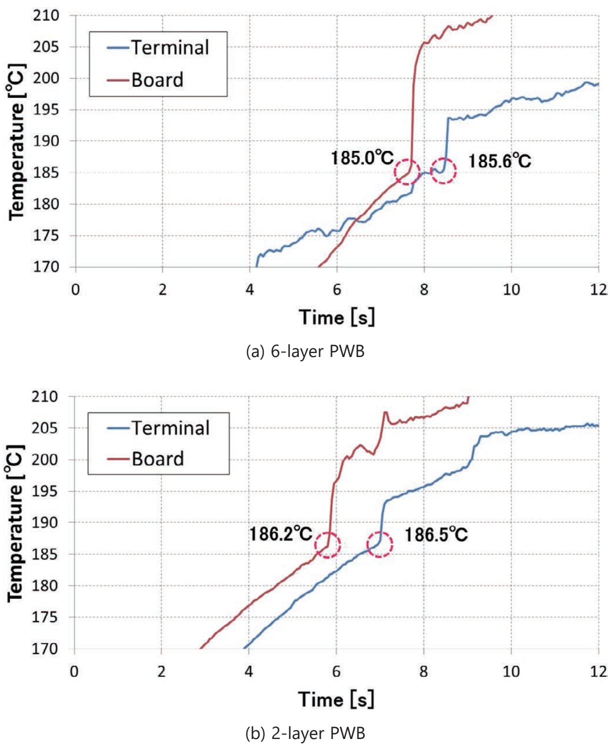
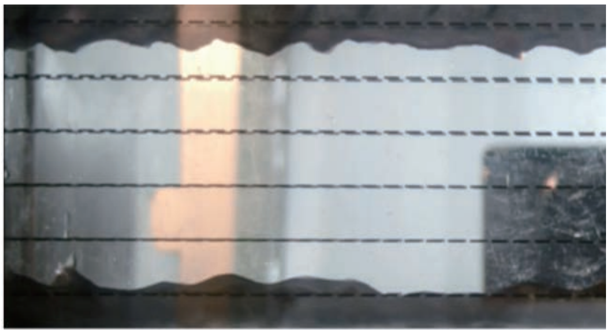


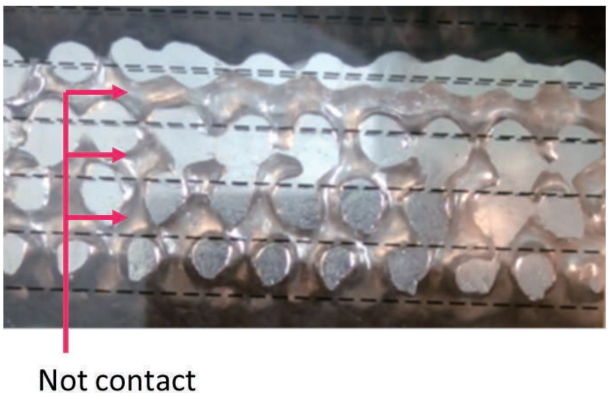
Fig. 4 Flow-up Temperature (Portions where temperature jumps up is shown)

4.2 Evaluation results of the first wave height

Figs. 5 and 6 show the conditions of solder contact with the PWB depending on the wave height of the first wave and the difference of the temperature profile. Contact of the solder wave with the PWB was confirmed by visual observation from above the glass panel that is carried instead of the PWB when the glass panel comes to the wave area. When the wave height was at the lower limit, the temperature below the PWB dropped temporarily. It was revealed by contact with the glass panel, that solder maintained contact with the PWB between each wave when the solder wave reached the upper limit of the PWB, but contact becomes local when solder wave was at the lower limit, and in certain areas, contact is not made. It was confirmed that loss on heating caused by non-contacting solder wave can be reduced if the wave height reaches the PWB upper limit. Because the soldering time in wave soldering is limited according to the specifications of the parts mounted on the PWB, it is especially important to prevent loss on heating during the soldering time in the case of the high-heat capacity PWB. So, in order to evaluate the contact condition of the lower surface of the PWB with the solder wave quantitatively, the area below the temperature curve under the PWB was calculated. Considering that heating by the solder wave can be obtained from the area enclosed by dashed line in Fig. 6, the calculation result indicated that the area reduced about 20% at the lower limit of the wave height.

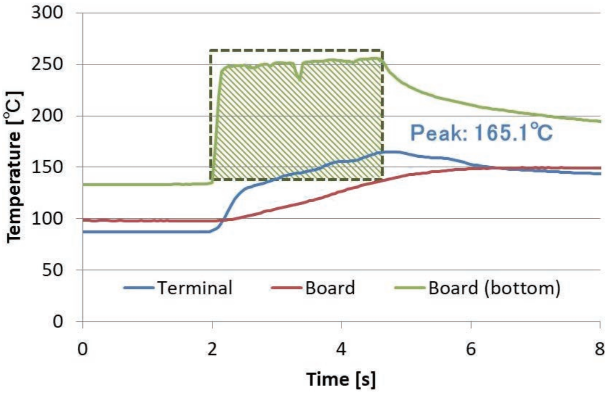


(a) At upper limit

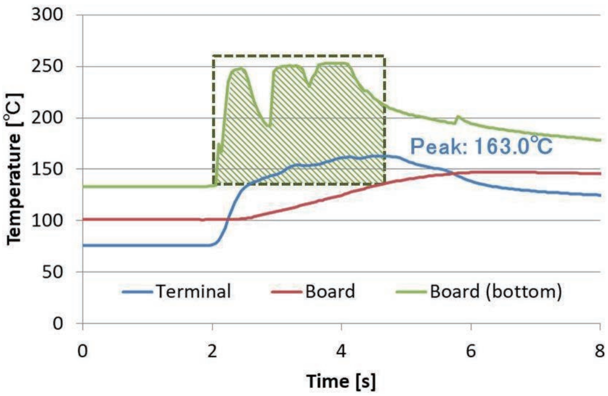


(b) At lower limit

Fig. 5 First Wave Height and Contact with Glass Panel



(a) At upper limit



(b) At lower limit

Fig. 6 First Wave Height and Temperature Profile (Portions of the first wave is shown)

The difference between peak temperatures of the PWB and the terminal was only a few degrees, although there was a difference of heating by about 20%, and the base metal temperature of the evaluation PWB did not reach 180°C (Fig. 6). Completion of flow-up before finishing of second wave is difficult unless temperature of the terminal is increased to almost flow-up temperature by the first wave. So the authors investigated the method to increase the terminal temperature to 180°C by the first wave.

The authors considered that the reason why the effect of the wave height was smaller than expected is that the wave height was different from the wave height where it penetrated into the through hole as wave height was defined as the height reaching the PWB. So evaluation was made again with the wave height raised 2 mm higher from the PWB upper limit by changing the setting of the equipment so that the solder reached the PWB upper limit in the through hole (Fig. 7). The temperature profile in that case is shown in Fig. 8. By raising the wave height to the upper limit in the through hole, the terminal temperature increased to reach 180°C. It was confirmed that the solder did not go up from the upper face of the through hole.

As the terminals of the self-standing electrolytic capacitor used were bent, it was difficult for the solder wave to penetrate into the through hole compared with the capacitor with the straight terminals. A cross section of the PWB with the terminal inserted cut at the center of the through hole viewed from the side is shown in Fig. 9. The authors consider that temperature difference was not apparent because effect of the wave height was reduced as solder wave could not easily penetrate into the through hole due to the bent terminal.

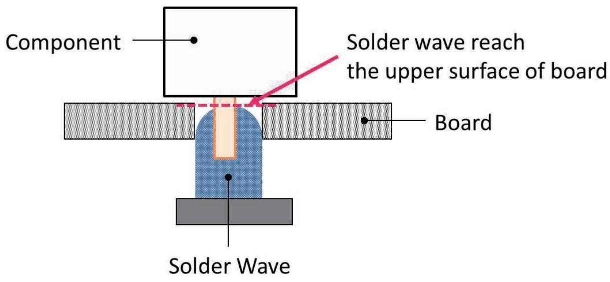


Fig. 7 Wave Height that reaches Upper Surface of the PWB in the Through Hole

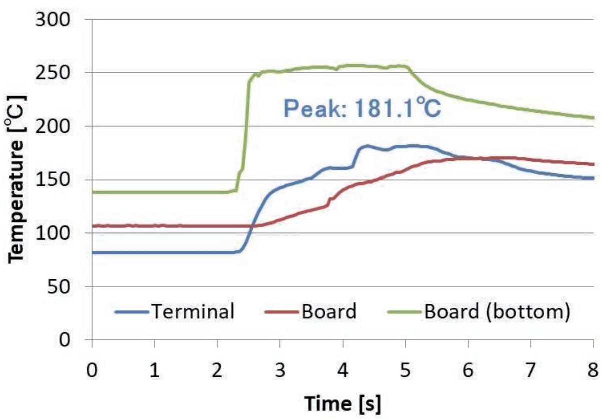


Fig. 8 Temperature Profile when Wave Height is Over Upper Limit (Portions of the first wave is shown)

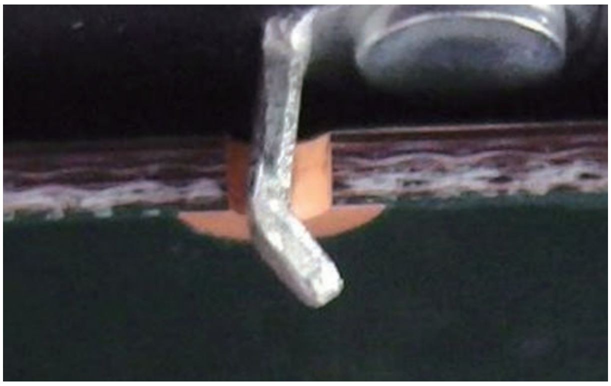


Fig. 9 Terminal in the Through Hole

Change of the solder swelling in the through hole for different wave height was observed from the side of the PWB using the X-ray penetration imaging (Fig. 10). The solder wetted area reached higher as the wave height increased, and it was confirmed that the solder reached the upper surface of the PWB when the terminal temperature reached 180°C (wave height at the upper limit in the through hole).

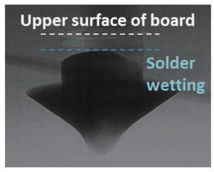
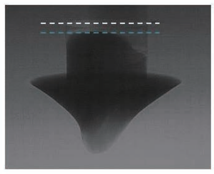
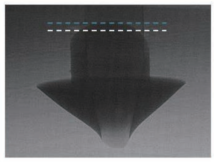
Wave height (Peak temperature)	Solder wetting
Lower limit (163.0℃)	
Upper limit (165.1℃)	
Upper limit at through hole (181.1℃)	

Fig. 10 Wave Height and Swelling in the Through Hole

Soldering time was investigated next. Fig. 11 shows the peak temperature vs. soldering time of the first wave. It is shown that the peak temperature increases linearly as the soldering time increased. It can be estimated that the peak temperature will reach 180°C when the soldering time is increased by one second to 3.5 seconds. As explained, the temperature of the terminal and the PWB changes depending on the wave height and the soldering time. The wave height and soldering time change with time due to blocking of the guide vane in the nozzle, solder level, etc. By quantifying the effect of wave height based on the data, the importance of the control items can be demonstrated. In addition, it is found that finer control of the process is required in order to respond higher heat capacity requirement.

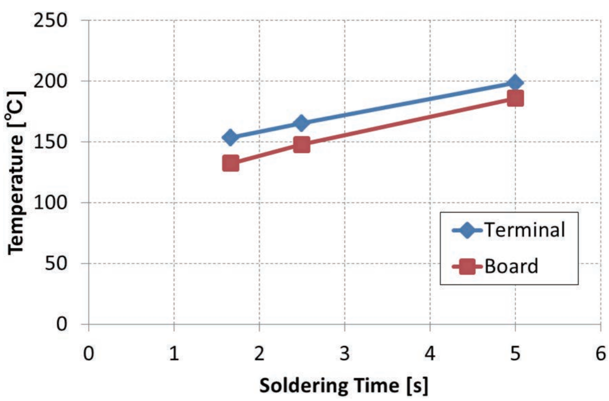
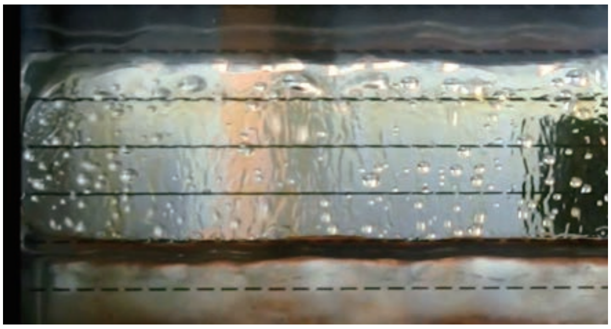


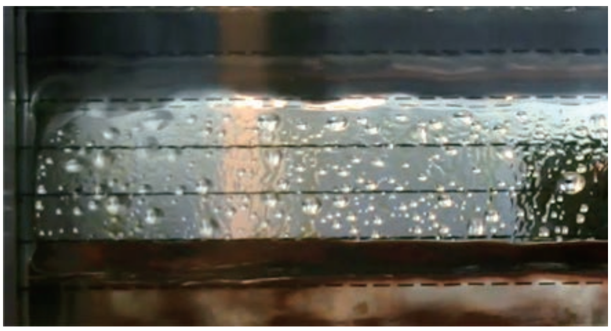
Fig. 11 First Soldering Time and Peak Temperature

4.3 Evaluation results of the second wave height

Figs. 12 and 13 show the conditions of solder contact with the PWB depending on the wave height of the second wave and difference in the temperature profile. Solder contact with the PWB was observed using the glass panel like in the case of the first wave. As the second wave is a large wave forming a lump, solder contact condition change as shown in the first wave caused by the wave height change cannot be observed and temperature under the PWB was stable when the wave height was at the lower limit. But width of contact with the glass plate was small because the shape of the second wave was a lump in mountain shape (Fig. 12). Loss on heating caused by no contact of the solder wave like in the case of the first wave does not occur in the case of the second wave, but it was found that a temperature decrease takes place due to the shorter heating time. The peak temperature difference was about a few degrees, and no significant difference was observed. By the equipment used in the experiment, the second wave height cannot be increased, which exceeds the PWB upper limit. It was shown that improvement of heating performance is difficult increasing the wave height of the second wave above the PWB upper limit.

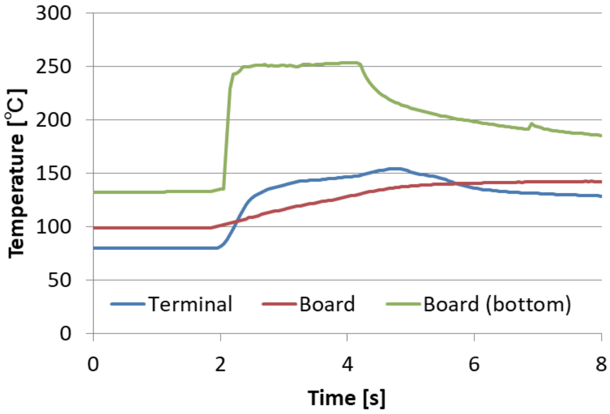


(a) At upper limit

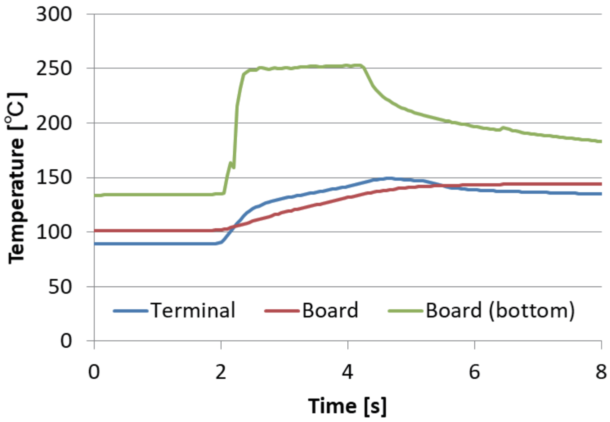


(b) At lower limit

Fig. 12 Second Wave Height and Contact with Glass Panel



(a) At upper limit



(b) At lower limit

Fig. 13 Second Wave Height and Temperature Profile (Portions of the second wave is shown)

4.4 Evaluation results of amount of flux applied

Fig. 14 shows the appearance of solder joints on the upper surface of the PWB and the condition of solder joints in the through hole obtained by X-ray penetration imaging when the amount of flux applied is changed. When the amount of flux applied is small, wetting of the terminal is not obtained, although solder reaches the upper surface of the PWB, and a proper solder joint is not formed. When the flux is applied too much, many voids are observed in the through hole. A more detailed evaluation is required to estimate appropriate amount of the flux, but a problem in the solder joint arises when the amount of flux applied is too much or too small. As the amount of flux applied is subject to change due to blocking of the application nozzle, it is important to prevent shortage or fluctuation of the amount by appropriate maintenance.

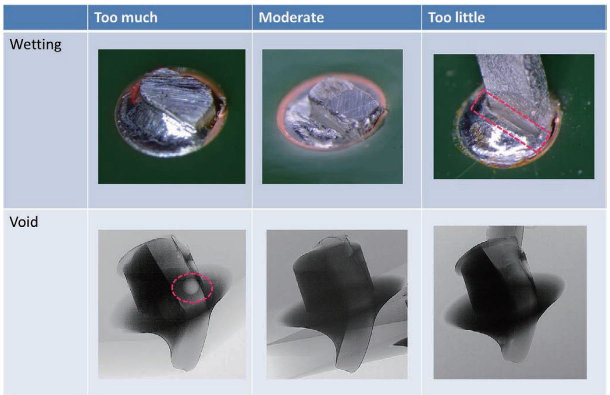


Fig. 14 Amount of Flux Applied and Solder Joint Condition

5. Conclusion

As it is essentially required to improve solder wave control skills of the engineer to improve quality of wave soldering, the relationship between the wave height and the temperature of the PWB and mounted parts are shown using the experiment data to demonstrate importance of solder wave control. As such an approach will contribute to improvement of the skills of the engineer, the authors intend to continue the study. It was also found that more delicate control of the solder wave is required for the PWB with higher heat capacity. Because such delicate control will not be possible by human ability alone, improvement of the skill will not be sufficient. The authors intend to continue the study on quantification and monitoring of the important control items, such as the wave height based on sensing technology. From the aspects of equipment and soldering conditions, adjustment of the wave height and soldering time is effective, but when the wave height is raised, a risk of solder going up from the other through holes in the PWB increases and soldering time needs to be limited to the extent to meet the heat resistance specifications of the mounted parts, so adjustment of the wave height and soldering time are effective only within the limited range. So the authors intend to improve soldering quality of the high-heat capacity PWB by development of the technology to improve heating performance of solder wave such as customized design of the nozzle.

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