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Occurrence of Non-Wetted Parts in Dip Soldering (Report-1) †

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Abstract

In dip soldering of electronics parts, the non-wetted parts produced on lead wires are depended on the immersion depth of them. In order to prevent the non-wetted parts, it was confirmed from this experiment that the immersion depth of 0.8 mm dia. lead wire must be limitted within about 1.6 mm. On the other hand, the depth recommended by JIS C5033 "Solderability Testing Method for Electronic Components" is 2 to 2.5 mm. This value was justified by appling a theoretical consideration and II type wetting process named in this paper.

KEY WORDS: (Dip Soldering) (Electronic Devices) (Defect) (Reliability)

1. Introduction

In the modern manufacture of electronics parts, the automatic dip soldering method of a printed wiring board and lead wires is generally employed for homogenizing the quality of soldered joints or increasing of workability and lowering of soldering cost. However, this method produces some defects such as non-wetted part, pinhole, bridging and icicle etc., because large numbers of soldered joints are simultaneously made by dipping once the printed wiring board into a bath of molten solder after dipping into a flux bath. These defects clearly effect the reliability of packaged printed wiring board, hence many researches are doing to prevent them. Especially, the non-wetted parts of soldered joints that have the majority in these defects have been reported to be almost prevented by inspecting the surface contamination on lead wire when it was received as a solid wire reel[1].

In this study, then, in order to know the mechanism of non-wetting phenomena in dip soldering, the area of local non-wetted parts occurred on the surface of copper specimen dipped in molten eutectic solder was measured as functions of the surface oxidized degree of specimen, the immersion temperature, time, depth, speed of specimen and flux activity, by using a commercial type meniscograph solderability tester.

From the otabined results, the wetting processes in dip soldering were classified into type I and type II. The wetting process of type I was observed when the specimen was dipped within the equilibrium height of negative meniscus by non-wetting liquid, and the type II was observed when the specimen was dipped deeper than the equilibrium height. The difference of both types was attributed to the fact whether the hydrostatic pressure of molten solder directly acted for the dipped part of specimen or not.

2. Materials Used and Experimental Procedures

2.1 Materials used

The use of lead wire is proper for the immersion test by the meniscograph tester, but tough pitch copper plate, the size is length 50 mm, width 5 mm, thickness 0.5 mm, was used in order to measure more easily the area of local non-wetted parts. In order to obtain the required oxidized surface conditions, the surface of these specimens as received was treated before the immersion test as follows;

1) Removal of grease and dust with acetone
2) Immersion of 3 sec in 0.5 wt% HNO_3 solution
3) Wash with water and acetone
4) After dry, oxidizing at 150°C for a required time in air

A cylindrical stainless steel vessel (dia. = 8 cm, height = 8 cm) filled with 61.9 wt% Sn-Pb eutectic solder of 3 Kg, was used as a solder bath, and was heated to a required temperature by an external electric heater. A type (non-activated) and D type (activated) fluxes shown in **Table 1** were used. Before the immersion test, the surface treated specimen was coated with each flux by dipping it for 4 sec to the flux bath at room temperature. In this dipping operation, the fluxed height of specimen was 3 mm over the height of its specimen dipped into the molten solder bath.

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Table 1 Compositions of fluxes used

Flux type	Constituent (wt%)				
	GLY[1)]	TEG[2)]	Rosin[3)]	IPA[4)]	AHC[5)]
A flux	65.0	35.0	-	-	-
D flux	-	-	34.9	64.8	0.3

1) Glycerin ($CH_2(OH)CH(OH)CH_2(OH)$)
2) Triethylene Glycol ($HOCH_2CH_2OCH_2CH_2OCH_2CH_2OH$)
3) Grade WW
4) Isopropyle Alcohol ($(CH_3)_2CHOH$)
5) Aniline Hydrochloride ($C_6H_5NH_2$ HCl)

2.2 Experimental procedures

The fluxed specimen was suspended down the longitudinal direction of specimen from the transducer moniter spring system of meniscograph tester and was down perpendicularly to make contact with a mirror-like solder surface and was taken down until a predetermined depth. At the depth the specimen was dipped for predetermined time and was drawn up at a constant speed. After that, the area of non-wetted parts produced on dipped part was measured by magnifing it 10 times by a profile projector.

3. Results and Discussions

In this study, the non-wetted part means the part that solder was not allowed to remain on the dipped part. **Fig. 1** is a typical example. These defects are seen downward at the dipped part and are the copper texture of specimen. And, the ratio of non-wetting area was calculated by the following equation (1);

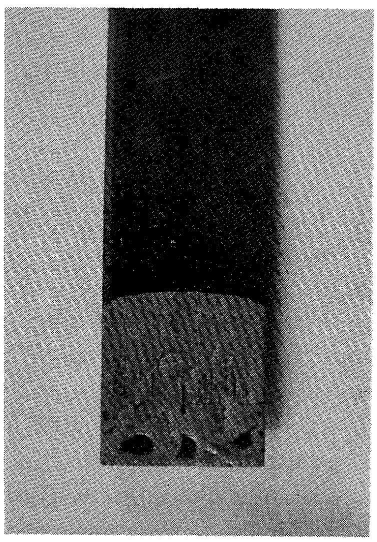

Fig. 1 Typical non-wetted parts appeared on surface of specimen

$$\text{Ratio of non-wetting area} = \frac{\text{The area of non-wetted part}}{\text{The area of non-wetted part + The area of wetted part}} \times 100\ (\%) \qquad \cdots\cdots (1)$$

3.1 Effect of immersion time

When the specimen heat-treated for 5 min at 150°C in air was used, the relationship between the ratio of the non-wetting area and immersion time was measured for an immersion depth of 4 mm, immersion speed of 8 mm/sec and solder temperature of 230°C. The result is shown in **Fig. 2** with A type and D type fluxes. The required time to reach a equilibrium rise height of solder was about 12 sec for A type flux and about 5 sec for D type flux. In spite of dipping over 12 sec, in both cases, the ratio of the non-wetting area was almost constant. From this result, the immersion time of each experiment described below was selected as 30 sec. Fig. 1 shows the appearance of the specimen dipped for 30 sec into molten solder with A type flux. As is visible in the photograph, the non-wetted parts concentrate upon the lower part of specimen dipped.

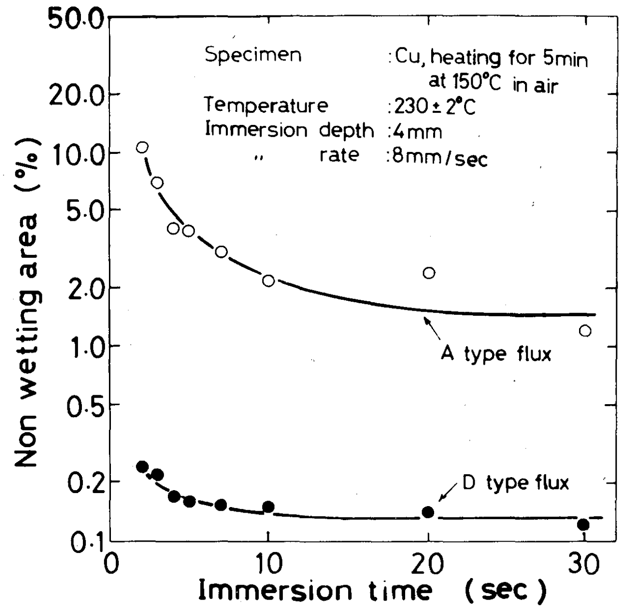

Fig. 2 Effect of immersion time on non-wetted area

3.2 Effect of immersion depth

Figure 3 shows the relation between the ratio of the non-wetting area and the immersion depth, by using the specimen same heat-treated and same immersion conditions as mentioned in above section. When A type flux

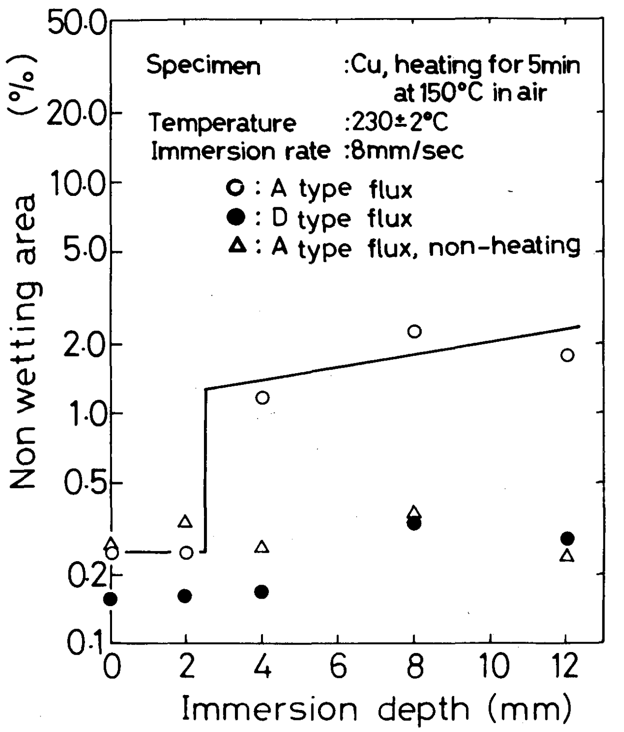

Fig. 3 Effect of immersion depth on non-wetted area

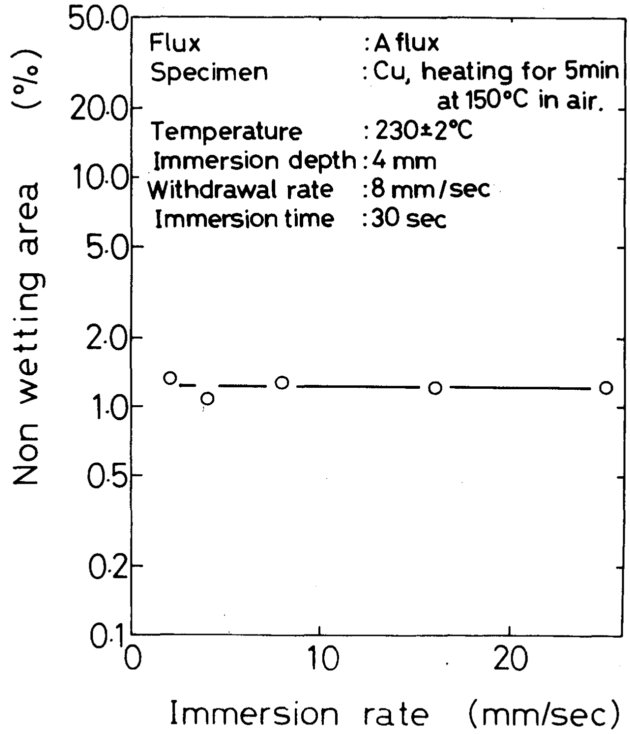

Fig. 4 Effect of immersion rate on non-wetted area

was used, the ratio of the non-wetting area changes suddenly at the range of depth between 2 mm and 4 mm. In dipping deeper than 4 mm, the majority in these non-wetted parts concentrated upon the lower part than about 2.5 mm from molten solder bath surface. However, as shown in the figure, the ratio of the non-wetting area was small and was not depended upon the immersion depth, when D type activated flux was used, or when A type non-activated flux and the specimen that was not heat-treated after acid treatment described in the section 2.1, were used.

3.3 Effect of immersion and drawn up speeds

The effect of immersion speed on the ratio of the non-wetting area was examined at the constant drawn speed of 8 mm/sec, by using same specimen heat-treated and same immersion conditions (the depth is 4 mm) as mentioned in above section. The result is shown in **Fig. 4** for A type flux. The immersion speed did not influence on the ratio of the non-wetting area within the experimental conditions described in this paper. The similar result was obtained also, when the drawn up speed was changed at the constant immersion speed of 8 mm/sec. These results can be attributed naturally to the facts that the non-wetted parts produced at the initial dipping time diminished gradually during the immersion time of 30 sec, as shown in Fig. 2, and the surface of solder bath was mirror-like.

3.4 Wetting processes in dip soldering

As shown in Fig. 1 and Fig. 3, the non-wetted parts were seen mainly on the lower side of dipping part, and also the ratio of non-wetting area increased suddenly at the range of immersion depth from 2 mm to 4 mm. Then, the experiments described below were made to investigate these phenomena.

3.4.1 Effect of hydrostatic pressure of molten solder

As shown in **Fig. 5** (a) and (b), the specimen heat-treated for 5 min at 150°C in air was dipped into molten solder to a predetermined depth without painting flux. After holding for 3 sec, 0.3 ml of A type flux was poured on the negative meniscus surface of molten solder, as shown in Fig. 5 (c). After the solder reached an equi-

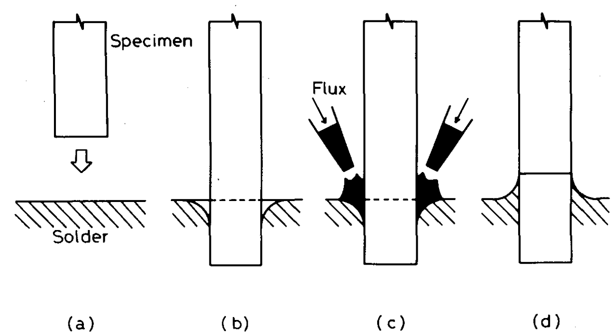

Fig. 5 Non-wetted state of no-fluxed specimen (b) and good wetted state (d) due to adding A type flux (c)

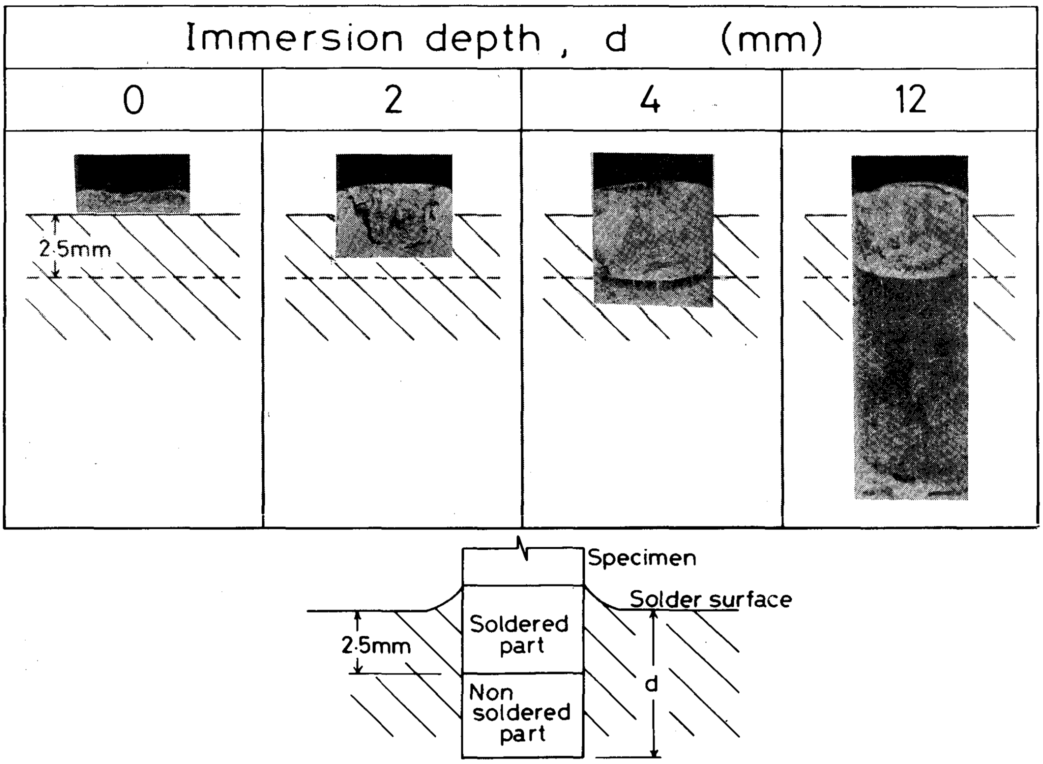

Fig. 6 Wetted part depending on immersion depth after experimental procedure shown in Fig. 5

librium rise height as shown in Fig. 5 (d), it was pulled up and the dipped part was observed. The result was shown in **Fig. 6**, by changing the immersion depth. As is visible in the figure, a boundary line at which fall backed 2.5 mm from the solder bath surface was distinguished in both depths 4 mm and 12 mm. The upper part from the boundary was wetted with the solder and the lower part from the boundary, at which the solder did not wet, was the copper texture of specimen.

This experimental fact showed that the flux poured did not penetrate into the gap between the specimen and molten solder because of the hydrostatic pressure of molten solder. On the other hand, at the depth of 2.5 mm, the hydrostatic pressure balances the downward force caused by the surface tension of a negative meniscus surface of molten solder and the supplied flux remains on the surface. Accordingly, in the case of shorter immersion depth than 2.5 mm, the solder wetted to all of the dipped part, and the ratio of non-wetting area was nearly 0.2%, for the immersion depth of 0 mm and 2 mm as shown in Fig. 3.

3.4.2 Classification of wetting processes

As above-mentioned, whether the hydrostatic pressure affects the plate surface of specimen or not is based on the immersion depth of specimen. So, when the specimen was dipped within 2.5 mm from the solder bath surface, the wetting process was named as I type, as shown in **Fig. 7** (a) and when the specimen was dipped below the depth of 2.5 mm, the wetting process was named as II type, as shown in Fig. 7 (b). In the case of II type wetting process, the flux painted on the AB part shown in Fig. 7 (b) is almost removed by the hydrostatic pressure of molten solder during dipping into the molten solder. By the removal of flux, consequenty, the non-wetted parts concentrate upon the lower dipped part of specimen as

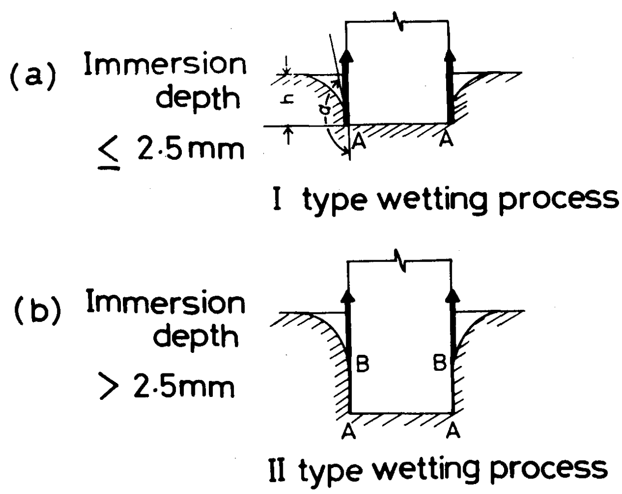

Fig. 7 Classification of wetting process

shown in Fig. 1 and the ratio of the non-wetting area increased suddenly on the range of depth from 2 mm to 4 mm as shown in Fig. 3. However, in the case of activated D type flux, it is clear from the result of Fig. 3 that the residual flux on the AB part has still an action for removing of copper oxide film, even if the hydrostatic pressure affected to the part.

3.4.3 Equilibrium height of negative meniscus of solder surface by non-wetting phenomenon

The equilibrium height of negative meniscus of solder surface by non-wetting phenomenon was 2.5 mm as shown in Fig. 6. So, the wider specimen 50 mm length, 30 mm width, 0.5 mm thickness was used for similar experiment shown in Fig. 5, in order to obtain the equilibrium height of negative meniscus in an infinite width plate. From this experiment, the boundary was distinguished at 3.6 mm from the solder bath surface.

Now, the equilibrium height (h in Fig. 7 (a)) of negative meniscus is given by following equation (2), which was obtained by modifing the published equation[2)] on an equilibrium rise height of positive meniscus;

$$h = 2\sqrt{\frac{\sigma_l}{\rho g}} \sin\left(\frac{\alpha}{2} - 45\right) \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where, σ_l; interfacial tension between solder and flux

ρ; density difference of solder and flux

g; gravity constant

α; contact angle

From the experimental results mentioned above, we obtained $\sigma_l = 457$ dyne/cm and 1.8 mm as the radius of curvature at h point, when $\alpha = 180°$, $h = 0.36$ cm, $\rho = 7.2$ g/cm^{3*} are substituted in equ. (2). On the other hand, from the similar experimental procedure shown in Fig. 5, the measured h value was 1.6 mm for a copper lead wire of 0.8 mm dia. and also 3.0 mm for a lead wire of 2.6 mm dia.. From these values, the radii of curvature on two conjugated planes at the h point of each wire are calculated as 1.8 mm and 3.2 mm for the wire of 0.8 mm dia. and also as 1.8 mm and 10.8 mm for the wire of 2.6 mm dia..

In **JIS C5033**[3)], the immersion depth of lead wire packaged on a printed wiring board is standardized as 2 to 2.5 mm. This value is larger than 1.6 mm of 0.8 mm dia. wire mentioned above. Consequently, the standardized depth is in danger of the occurrence of non-wetted parts by the hydrostatic action of molten solder.

3.5 Lowering of non-wetted part in II type wetting process

As is considerable from equ. (2), the equilibrium height, h, may increase with decrease soldering temperature, so that the shift from II type to I type wetting process may occur and the non-wetted part may decrease. So, the relation between the ratio of non-wetting area and soldering temperature was obtained for the specimen heat-treated for 5 min at 150°C in air, the immersion depth of 4 mm, the immersion time of 30 sec, and with A type flux. The result is shown in **Fig. 8** and the ratio of non-wetting area is least at about 260°C. From this result, the decreasing of the non-wetted part in the temperature range of 260 to 350°C agrees with the physical consideration of temperature dependence on equ. (2) mentioned above. However, at the lower soldering temperature than 260°C, the non-wetted part increased in spite of increasing of h. One reason for this discrepancy may be that the reducing action for oxide film by used flux decreases with lowering of the soldering temperature. Then, in order to increase the reducing action of flux, aniline hydrochloride was added to the A type flux and the effect on the ratio of non-wetting area was measured at a constant temperature of 230°C, namely, at a constant h. As shown in **Fig. 9**, on the specimen that was not heat-treated after acid-treatment described in section 2.1, the ratio of the non-wetting area did not show the concentration dependence of adding activator. However, the ratio of non-wetting area for both of heat-treated specimens decreased linearly with the concentration of activator and these two straingt lines intersect at about 5 wt% aniline hydrochloride. This result made it possible to consider that the decline in the reducing action of A type flux with lowering of soldering temperature may be

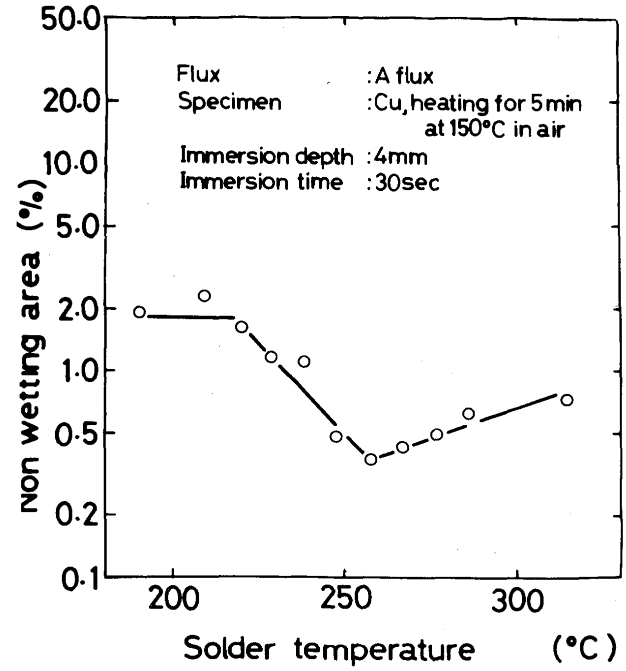

Fig. 8 Effect of solder bath temperature on non-wetted area

* ρ of solder = 8.4 g/cm^3, ρ of flux = 1.2 g/cm^3

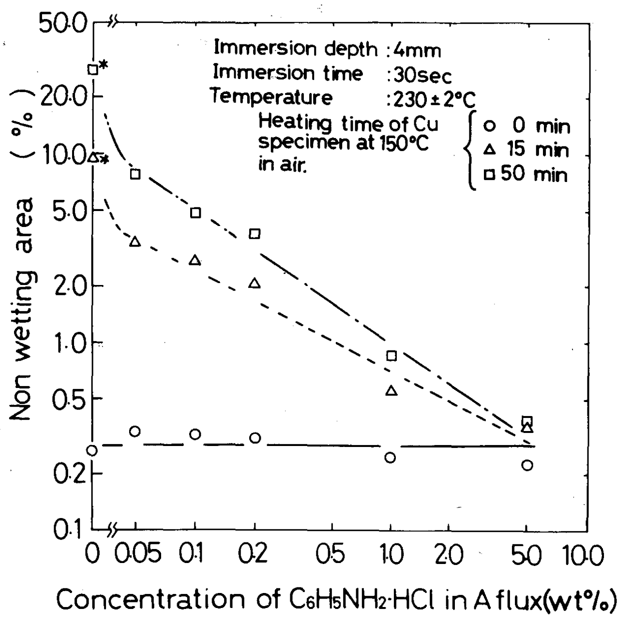

Fig. 9 Effect of activator added in A type flux on non-wetted area

compensated by adding aniline hydrochloride of 5 wt% to it.

Furthermore, the mark, *, in this figure shows the case which the equilibrium rise height of solder does not reach the solder bath surface, that is negative meniscus, as shown in **Fig. 10**. As shown already in Fig. 7 (b), in the II type wetting process, the flux painted on the AB part is pushed upward by the hydrostatic pressure of molten solder during dipping. And the pushed flux may contain the reaction products by the reducing reaction for oxide film on the surface of specimen, so that the activity of the flux, including the pushed flux, painted on the upper part than the AB part may decrease. If this consideration is right, the thicker the oxide film on specimen is, the more inferior the activity of the pushed flux is. Then, the acid-treated specimens were heated at 150°C in air for various times, in order to change the thickness of oxide film on specimen, and the effect on the ratio of the non-wetting area was examined with A type flux. As is visible in **Fig. 11**, the thinner the oxide film is, the smaller the ratio of non-wetting area is. And also, the activity of A type flux declines as the specimen is heated for over 10 min at 150°C in air.

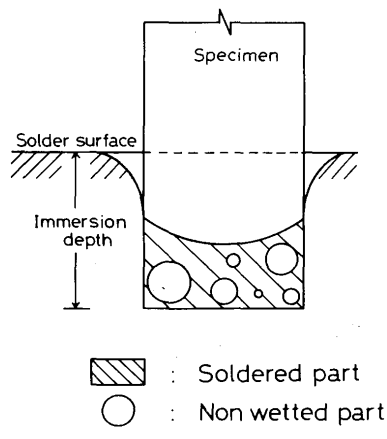

Fig. 10 Poor wetted state, showing equilibrium wetting height withdrawn from solder bath level

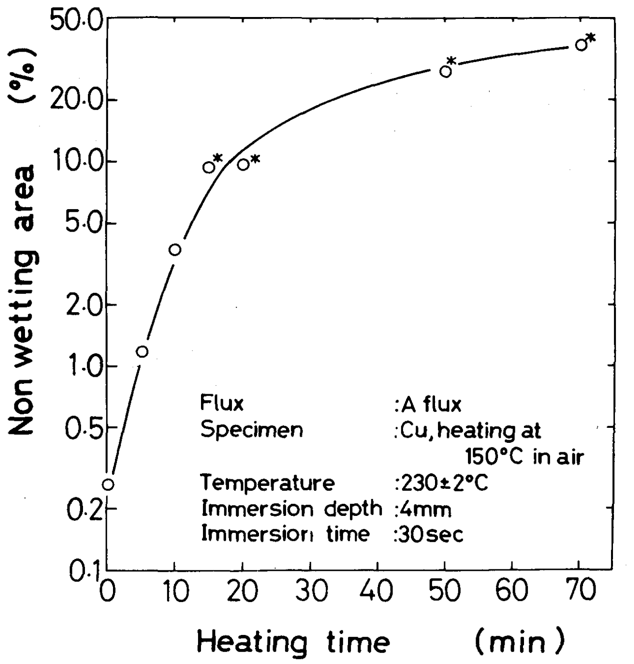

Fig. 11 Relation between non-wetted area and heating time of specimen in air at 150°C

4. Conclusions

The area of local non-wetted parts occurred on the surface of copper specimen dipped in molten eutectic solder bath was measured as functions of the surface contamination of specimen, the immersion time, depth, rate etc, of specimen and the activity of used flux, by using a commercial type meniscograph solderability tester and a profile projector.

The results obtained were as follows;

(1) The oxide film on specimen greatly influenced the occurrence of non-wetted parts. Before dipping, when the specimen was heated at 150°C within 10 min in air, the ratio of non-wetted area to the soldered area of specimen was below a few percent.

(2) The ratio of non-wetted area was depended on the immersion depth of specimen. When the depth equals a equilibrium height of negative meniscus by non-wetting liquid, or is below, the ratio was fairly small. This case was named as I type wetting process. However, when the depth is over the equi-

librium height, the ratio increased with increasing of the depth, because the flux painted on specimen was removed by the hydrostatic pressure of molten solder. This case was named as II type wetting process.

(3) The equilibrium height of negative meniscus was 3.6 mm for copper plate of infinite width and eutectic solder of 230°C. From this value, the radius of curvature at the height was calculated as 1.8 mm. Moreover, the equilibrium height of negative meniscus for a lead wire of 0.8 mm dia. was measured as 1.6 mm. In this case, the radii of curvature on two conjugated planes at the height of negative meniscus were calculated as 1.8 mm and 3.2 mm respectively.

(4) For a lead wire of 0.8 mm dia., the immersion depth of 2-2.5 mm standardized by JIS C5033 belongs to II. type wetting process in our experiment.

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3) JIS C 5033 : Solderability Testing Method for Electronic Components (1974)