Some Considerations on Solder Flow-Up into Plated-Through Holes

The effects of joint clearance and other soldering parameters are evaluated from the viewpoint of joint reliability

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Introduction

As a result of the development of high density packaging of electronic equipment, printed wiring boards with plated-through holes are widely used as a means of obtaining high density printed wiring.

To meet the demand for high productivity, mass soldering processes such as dip soldering and wave soldering are generally employed for making a number of soldered joints on a printed wiring board simultaneously.

One of the important requirements for mass soldering is that solder should flow up into plated-through holes uniformly and sufficiently to assure high reliability of soldered joints on printed wiring boards (Ref. 1).

It is known that, in the case of printed wiring boards without plated-through holes, the rate of producing imperfect solder fillets increases as the clearance between holes of the boards and lead wires of components increases (Ref. 2).

However, only a few reports have been published to date regarding the relationship between the clearance and solder flow-up into plated-through holes (Refs. 3-5).

This paper describes the results of experiments conducted to evaluate these relationships.

Experimental Procedure

Test pattern printed wiring boards as shown in Fig. 1 were manufactured by electroless plating process, by which various landless plated-through holes were provided, as follows:

1. Hole diameter (d) — 0.7, 0.8, 0.9, 1.0, 1.1 and 1.2 mm (0.028, 0.031, 0.035, 0.039, 0.043 and 0.047 in.)
2. Total number of holes — 9,000
3. Board thickness — 1.0, 1.6 and 2.0 mm (0.039, 0.063 and 0.079 in.)
4. Board material — glass-epoxy, copper clad laminates (NEMA, G-10)
5. Plating thickness — approx. 0.025 mm (0.001 in.)

In addition, dummy components A and B, having different heat capacities, were prepared (see Fig. 2).

The lead wires of the components were tin-lead plated copper wires having a diameter (ϕ) of 0.5 mm (0.020 in.), which gave the following clearances:

Clearance (d-ϕ) — 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 mm (0.008, 0.012, 0.016, 0.020, 0.024 and 0.028 in.)

Dummy component A had a comparatively large heat capacity and was thermally equivalent to a ½ watt-type solid resistor with its lead wire soldered at a location close to the resistor itself. Dummy component B

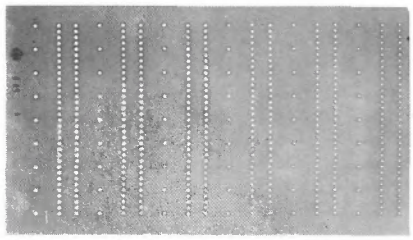

Fig. 1 — Test pattern printed wiring board

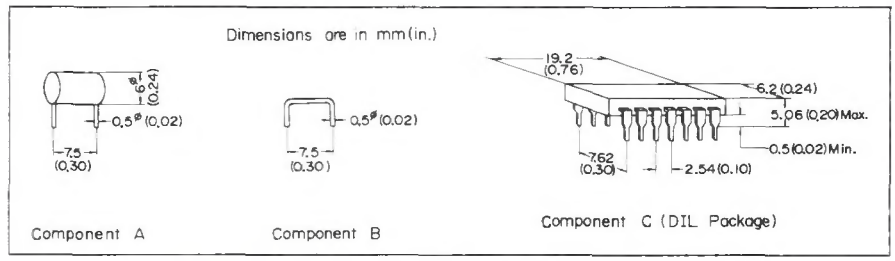

Fig. 2 — Components A, B and C of varying heat capacity

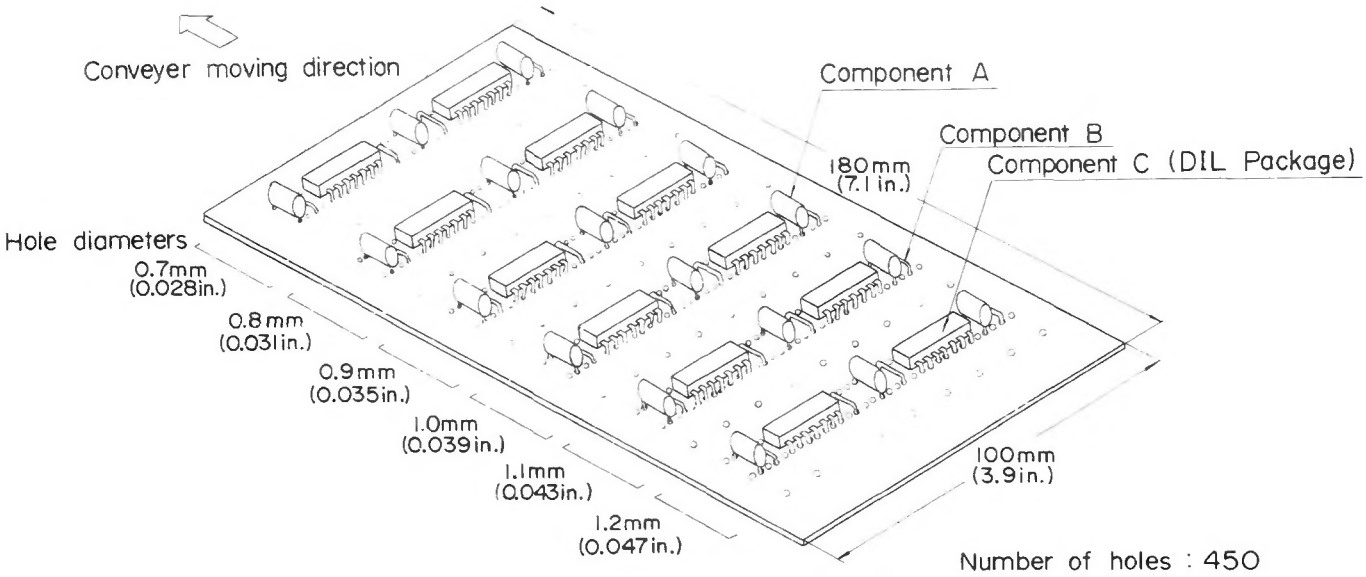

Fig. 3 — Components mounted on the printed wiring board

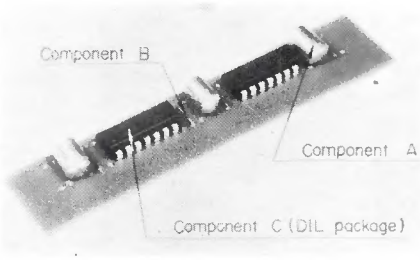

Fig. 4 — Test piece after soldering

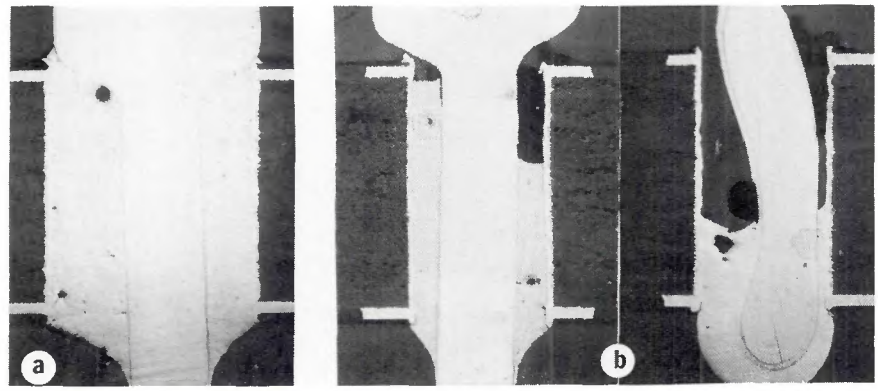

Fig. 5 — Examples of solder flow-up into plated-through holes. (a) A perfect joint; (b) two types of imperfect joints

represented components having a very small heat capacity.

In addition, DIL packages with leads of silver-plated Kovar wires having a cross-sectional area of 0.25 × 0.5 mm (0.010 × 0.020 in.) were prepared as component C, as also shown in Fig. 2.

These three types of components were mounted on the test pattern printed wiring boards decribed above and soldered in position, as shown in Fig. 3.

To confirm solderability of the boards, insertion of the lead wire was completely omitted for some of the plated-through holes, and soldering was simultaneously applied to all holes.

The conditions for soldering employed in this case were as follows:

1. Equipment — wave soldering machine
2. Solder — 63/37 tin-lead solder
3. Temperature — 235, 245 and 255 C (455, 473 and 491 F)
4. Conveyer speed — 0.3 to 1.5 m/min (12 to 59 in./min) approx.
5. Preheating — approx. 80C (176F), approx. 1 min
6. Flux — activated rosin flux

Figure 4 is a photograph of the test piece after soldering.

Test pieces were examined after soldering by stereoscopic microscope, using a magnification of ×15. The state of solder flow-up into the plated-through holes was estimated visually, and those flow-ups which failed to reach over 80% of board thickness were counted as imperfect. Concurrently, a sectional inspection of holes was applied to certain test pieces. Examples of perfect and imperfect flow-ups are illustrated in Fig. 5.

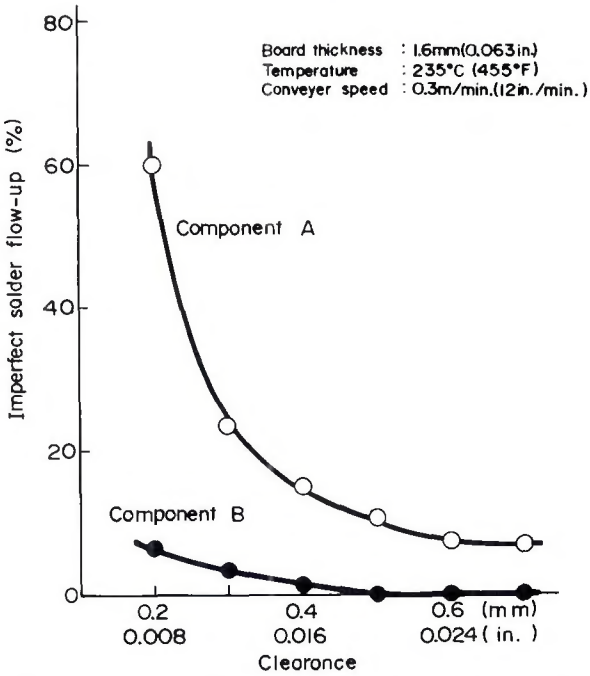

Fig. 6 — Imperfect solder flow-up vs. clearance using component heat capacity as a parameter

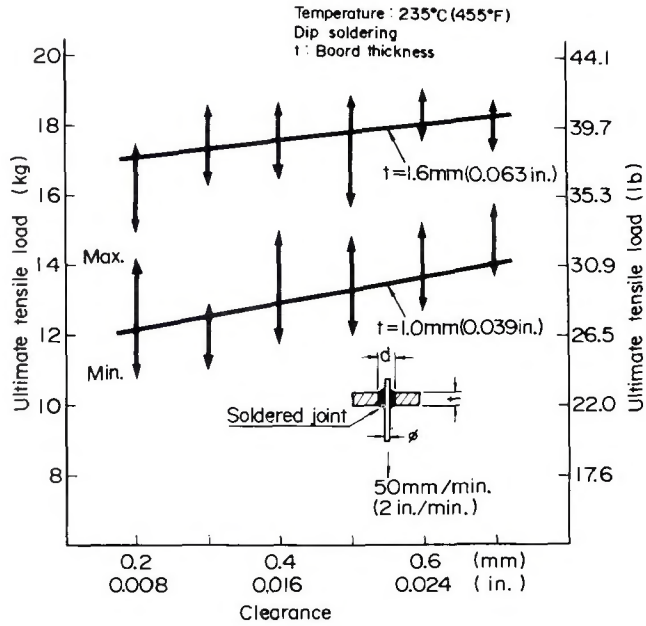

Fig. 7 — Ultimate tensile load vs. clearance

Results and Discussion

The relationship between the clearance and the rate of imperfect solder flow-ups in the plated-through holes, where heat capacities of components were used as a parameter, is shown in Fig. 6.

In the case of a plated-through hole, when the clearance became smaller, the rate of imperfect solder flow-ups grew proportionately larger, and the solder fillet formation also became poor.

This tendency became obvious when a component possessing a large heat capacity was inserted into the hole. The principal factors conceivable in this regard are that the volume of flow-up solder into the plated-through hole decreases when the clearance becomes smaller, and that the thermal energy applied to the soldered joint decreases because relative distance from the heat source becomes greater in this case (Refs. 6-8).

The relationship between the clearance and the ultimate tensile load on printed wiring boards with thicknesses of 1.6 mm (0.063 in.) and 1.0 mm (0.039 in.) is shown in Fig. 7. The results of measurement at soldered joints where the solder flow-up was 100% are shown in the figure. The shearing length of each soldered joint of a 100% solder flow-up on a 1.0 mm thick (0.039 in.) printed wiring board, by considering the solder fillet, is approximately 1.2 mm (0.047 in). This length equals the shearing length of a soldered joint where the solder flow-up is 70% of the board thickness on a 1.6 mm thick (0.063 in.) printed wiring board.

When the ultimate tensile load is proportional to the shearing length of the soldered joints, it can be seen from Fig. 7 that the ultimate tensile load of over 20 lb (9.07 kg) prescribed under MIL-P-55110B and MIL-P-55640A is obtainable on a 1.6 mm thick (0.063 in.) printed wiring board, provided that the solder flow-up is over 70%. In these experiments, however, allowing 10% margin, those in which the solder flow-up into the holes was less than 80% were judged as imperfect.

Similar test results obtained by mounting the DIL package on 1.6 mm thick (0.063 in.) and 2.0 mm thick (0.079 in.) printed wiring boards are shown in Fig. 8, in which the clearance is shown as a difference between the long side of the lead wire cross-section of the DIL package and the hole diameter. It is evident from these test results that the rate of imperfect solder flow-ups into the plated-through holes, where the clearance is 0.3 to about 0.4 mm (0.012 to about 0.016 in.), is reduced to a value which satisfies mass solderability.

Thus, in designing a printed wiring board with plated-through holes, setting the clearance at 0.4 mm (0.016 in.) or more is recommended from the viewpoint of solder flow-up. This value is not inconsistent with the clearance value required for an automatic insertion machine used for inserting electronic components into the printed wiring board holes (Refs. 9,10).

The relationship between the clearance and the rate of imperfect solder flow-ups, where the conveyer speed of the wave soldering machine was rated constant and soldering temperature was used as a parameter, is shown in Fig. 9. It is evident from the figure that better solder flow-ups are obtainable by setting the soldering temperature higher when the clearance is small.

Shown in Fig. 10 are similar test results where the soldering temperature was retained at 235 C (455 F) and 245 C (473 F), and the conveyer speed was changed. It can be seen from this figure that, when the conveyer speed is slower (that is, when the soldering time is longer), the rate of imperfect solder flow-ups decreases; particularly, when the clearance becomes smaller, the tendency becomes more pronounced.

In other words, Figs. 9 and 10 suggest that, when the clearance becomes smaller, imparting a larger volume of thermal energy to the soldered joints is necessary for obtaining good solder flow-ups. It is evident in this case that the reaction temperature and reaction time of the soldering flux are closely related, and inclusion of considerations for these factors in the discussion may therefore be necessary.

The relationship between the conveyer speed of a wave soldering machine and the rate of imperfect solder flow-ups, where soldering temperature was used as a parameter, is shown in Fig. 11. The figure pertains to an instance where DIL packages were soldered into plated-through

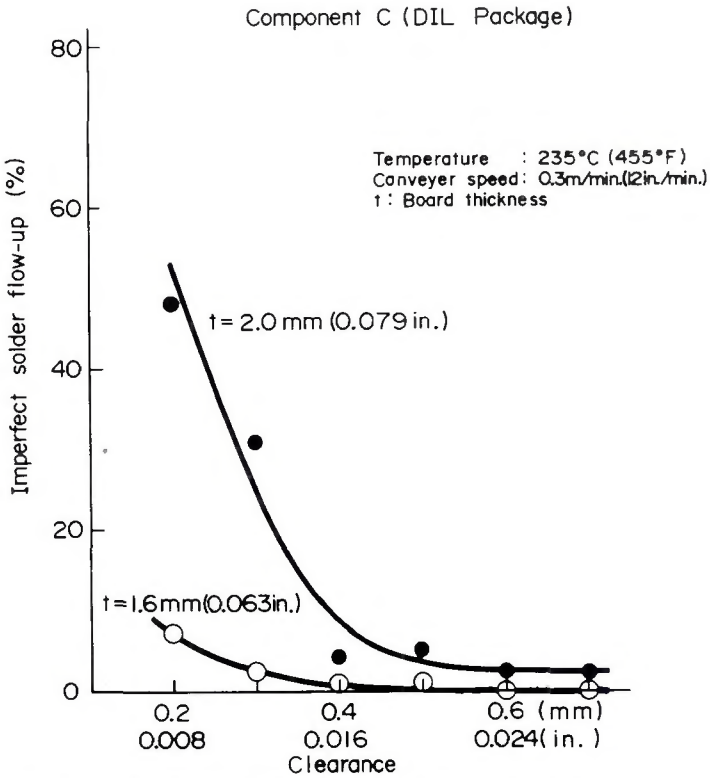

Fig. 8 — Imperfect solder flow-up vs. clearance for DIL packages

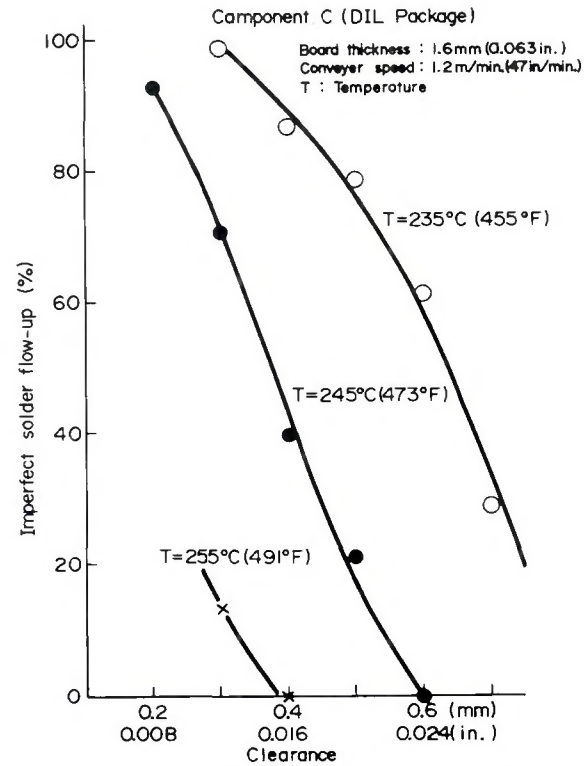

Fig. 9 — Imperfect solder flow-up vs. clearance using solder temperature as a parameter

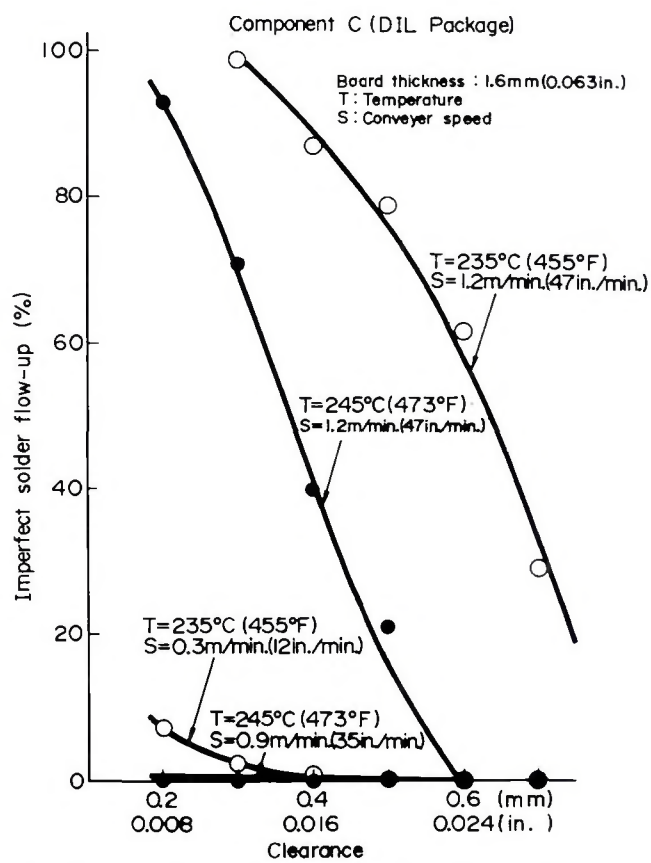

Fig. 10 — Imperfect solder flow-up vs. clearance using conveyer speed as a parameter

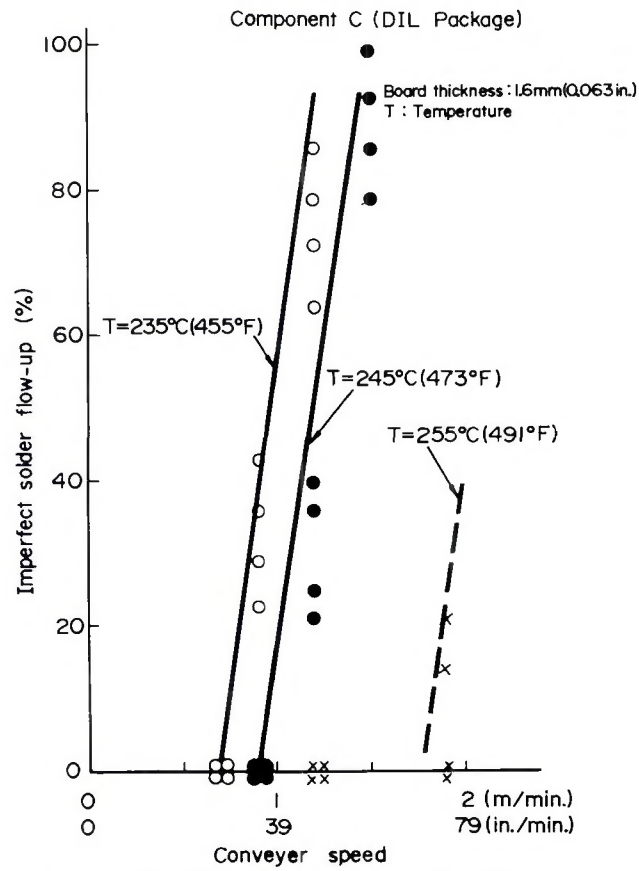

Fig. 11 — Imperfect solder flow-up vs. conveyer speed

holes to obtain a clearance of over 0.4 mm, indicating ultimate working conveyer speeds whereby good solder flow-ups are obtainable. For instance, it is evident from Fig. 11 that, when the soldering temperature is rated at 245 C, the conveyer speed must necessarily be below 0.9 m/min (3 ft/min).

Conclusions

The results of experimental studies on the relations of clearance between the diameter of plated-through holes on printed wiring boards and component lead wire diameter with solder flow-ups were summarily discussed in this report.

It has been clarified, from the viewpoint of solder flow-up that, in the case of a 1.6 mm thick printed wiring board, a size which is employed most frequently, the desirable minimum clearance is 0.4 mm (0.016 in.), provided that it lies within the conditions for experiments conducted herein.

Regarding relations between the soldering flux and the conditions for soldering, and relations between the solder fillet formation and the reliability of soldered joint, detailed studies are now in progress.

Acknowledgment

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