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SOLDER LEVELING
OF PRINTED
WIRING BOARDS

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ABSTRACT

Tin-lead coated printed wiring boards were subjected to a solder leveling process, naturally stored for various lengths of time, and then evaluated for solderability using the Pessel Spread Factor Test and the Edge Dip Test.

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SUMMARY

This investigation was undertaken to evaluate the solder leveling process for use in the fabrication of printed wiring boards at Bendix Kansas City. The thickness of the solder-leveled coating was measured. Two solderability tests were used to determine the solderability of the solder-leveled surface after various storage times. Specially designed printed wiring boards were fabricated that included solderability test samples. Tin-lead coated printed wiring boards were solder leveled and stored for various lengths of time in order to measure solderability after storage.

The findings of the work presented in this progress report are as follows.

- The thickness of the solder-leveled coating is nominally 55 micro-inches, regardless of the temperature or pressure of the leveling fluid. A temperature of 430°F and a spray pressure of 60 psig produce the least variation in thickness.
- The solderability of a solder-leveled surface decreases with time. Printed wiring boards stored up to 5 months have so far been tested. This effect is still being investigated but the decrease in solderability apparently occurs quite rapidly during the first two or three months after solder leveling and then tends to level off within the range of good solderability.

DISCUSSION

SCOPE AND PURPOSE

Higher circuit densities and smaller diameter through-hole requirements for tin-lead plated printed wiring boards are creating production problems. Plating tin-lead alloys on printed wiring boards necessitates excessive build-up of tin-lead alloy plate on conductor paths in order to achieve desirable plating thickness completely through a plated-through hole. This can result in slivering of the tin-lead plate overhang after etching and during assembly. On high circuit density printed wiring boards, slivering is detrimental as it can result in electrical shorting.

Hot oil fusing (also referred to as hot oil reflowing) of etched printed wiring boards is used to melt and reflow the tin-lead plating. This eliminates the slivering problem but can result in the plated-through holes becoming filled with solder. Slinging is a process where the board is sharply rapped on its edge while the solder alloy is still molten from the reflowing process. Slinging a printed wiring board removes some excess solder from the conductor paths and opens the majority of the plated-through holes. Slinging, however, does not adequately remove solder from plated-through holes and can cause delaminations of the glass-epoxy.

Solder leveling is a process whereby the tin-lead coating (electroplated or hot solder dipped) on etched printed wiring boards is melted and the excess removed. This is done with a high-pressure spray of a hot, proprietary liquid (such as a polyalkylene glycol) that melts and removes the excess tin-lead and leaves a thin, fused coating that is uniform in thickness. Figure 1 shows a printed wiring board being processed by a solder leveling machine. Solder leveling eliminates slivering, excess solder in holes, and delaminations caused by slinging.

Solder leveling is also a solderability test. Since the process melts the tin-lead, it produces an effect similar to actual soldering. Any solderability problems with the board are revealed by the solder leveling process in the form of exposed copper, nonwetting, or dewetting of the solder coating. It also provides a check on the composition of the tin-lead coating; a high lead content coating will not be completely melted and removed and lead-rich globules will remain on the board after leveling (Figure 2).

The purpose of this project is to evaluate solder leveling as a means of improving Bendix fabrication and assembly techniques for solder-coated printed wiring boards.

While solder leveling provides many benefits, several areas must be studied. One area is the thickness and chemistry of the solder layer resulting from a

Figure 1. Solder Leveling Machine in Operation

HIGH-LEAD SOLDER PLATING
AFTER SOLDER LEVELING (27X)

HIGH-LEAD SOLDER PLATING
AFTER SOLDER LEVELING (27X)

EXPOSED COPPER AND HIGH-LEAD
SOLDER PLATING AFTER SOLDER
LEVELING (27X)

EXPOSED COPPER AFTER SOLDER
LEVELING (27X)

Figure 2. Defects Revealed After Solder Leveling

solder leveling operation and how they affect solderability after storage. This report presents the results of an investigation of the solder thickness after solder leveling and of the solderability of solder-leveled surfaces naturally stored for up to five months.

This is a progress report of work being done under the direction of W. A. Mulholland in the Materials Engineering Laboratory and covers efforts pursued from May, 1970, through February, 1971. The estimated completion date for the project is March, 1972.

PRIOR WORK

As a result of vendor claims regarding the solder leveling process, B. T. Lampe investigated the feasibility of using a solder leveling process to produce solderable printed wiring boards. A limited number (14) of boards were solder leveled by a supplier of solder leveling equipment. These were evaluated for solderability two weeks after leveling and after storage of up to 9 months. The results indicated that the process might be useful provided the solderability would be adequate and there was no degradation of the printed wiring board. This feasibility study was reported in a Bendix Internal Memorandum.¹

ACTIVITY

Experimental

Tin-lead plated printed wiring boards were leveled using several temperatures and spray pressures. The thicknesses of the residual coatings were measured metallographically. Based on these findings, 430°F and 60 psig were selected for preparing all the boards used in the subsequent tests. The boards were introduced into and removed from the hot spray at 1 inch-per-second (ips) with an essentially zero dwell time.

Two different tests were used to determine solderability of the solder-leveled surfaces, the Edge Dip Test and the Pessel Spread Factor.²

Edge Dip Test. The Edge Dip Test is the most widely accepted solderability test in the electronic industry. It is defined in MIL-STD-202D, Method 208B. The part is tinned in a solder pot under controlled conditions and solderability is determined by visual inspection. The dwell time in the solder, the immersion rate, and the withdrawal rate are controlled by an automatic dipping device. A nonactivated, rosin-base flux is used and the temperature of the molten solder is closely controlled. The criteria for acceptable solderability is a minimum of 95-percent solder coverage of the surface being tested. The balance of the surface may contain small pin holes, dewetted areas,

rough spots, or uncoated basis metal provided such defects are not concentrated in one area. The test does not provide a numerical measure of solderability. A visual interpretation of the results is required. In order to be used as a production or inspection test, visual standards are necessary. The test can be either nondestructive or destructive; it is not a good test for plated-through holes.

Pessel Spread Factor. The Pessel Spread Factor measures solderability by allowing molten solder to spread on the surface for a specific length of time and determining the area of spread. The test conditions used were:

Test temperature	450 ± 10°F
Flux	Nonactivated, water-white rosin in alcohol (Alpha 100-30)
Solder	20 mm ³ preforms of 63Sn-37Pb
Test time	Test specimen heated for total of 30 seconds

The surfaces to be tested were fluxed with the solder preform in place. The test specimen was lowered onto a solder bath surface at a rate of 1 ips and allowed to heat for thirty seconds. Between twenty and twenty-five seconds were required for the preform to begin melting from heat conducted through the laminate. After spreading, the test surface was removed from the solder bath surface at a rate of 1 ips and allowed to cool. Lowering and raising of the test surface was done automatically.

The better the solderability of the surface the greater the amount of spread. The amount of spread has been determined by some workers by measuring the area covered by the solder. Since this is a time-consuming process, Pessel and others estimated the area by measuring the maximum height of the spread solder and calculating a spread factor as:

$$\text{Spread Factor (percent)} = \frac{D - H}{D} \times 100$$

Where D = Diameter of a sphere with a volume equal to the volume of the solder used, and

H = Height of spread solder.

Spread Factors were determined in this work. A dial indicator was used to measure the height. The scale of solderabilities assigned various spread factors is given in Table 1.

Table 1. Relationship of Spread Factor to Solderability

Solderability Description	Percent Spread Factor
Excellent	90 to 100
Very good	85 to 90
Good	80 to 85
Adequate (Fair to good)	70 to 80
Poor to fair	60 to 70
Very poor	Below 60

A printed wiring board was designed that incorporated five test specimens each for the two solderability tests. The 175 printed wiring boards fabricated were either tin-lead-plated, solder-dipped, or uncoated copper. Part of each type of printed wiring board was coated with a rosin and alcohol mixture to determine whether the coating would help preserve the solderability during storage. The samples were made from 0.062 inch thick Formica laminate (FR-45), clad on both sides with 1-ounce copper. Table 2 lists the specimen types, storage times, and storage conditions that were used for this determination.

Results and Discussion

One of the investigations undertaken was to determine whether or not the thickness of the solder coating can be controlled by varying the spray pressure and temperature during solder leveling. It was thought that lower temperatures and pressure settings would result in thicker coatings. This, however, was not the case. Regardless of temperature or pressure settings, the coating thickness was approximately 55 micro-inches. The higher pressure settings resulted in coatings with less variation in thickness. The coating thickness did not appear to be influenced significantly by varying temperature. Figure 3 gives the results of the optimum coating thickness investigation. The inherent error, associated with microscopically measuring millionths of an inch, can be large and should be recognized when reviewing the data.

The total coating thicknesses, given in Figure 3, are comprised of an inter-metallic compound layer and a free-solder layer. Distinction between the two layers was accomplished using metallographic techniques and suitable etchants. Each of the layers account for about half of the total thickness. Figure 4, View A, shows the total thickness after solder leveling.

Table 2. Specimen Types, Storage Times and Storage Conditions

Specimen Types of Printed Wiring Boards Copper*† Rosin-coated copper† Tin-lead plated copper**† Rosin-coated, tin-lead plated copper† Solder-leveled, tin-lead plated copper Rosin-coated, solder-leveled, tin-lead plated copper Tin-lead solder-dipped copper***† Rosin-coated, tin-lead solder-dipped copper† Solder-leveled, tin-lead, solder dipped-copper Rosin-coated, solder-leveled, tin-lead solder-dipped copper****	Natural Storage Times 4 weeks 6 weeks 8 weeks 10 weeks 3 months 4 months 5 months
Storage Conditions Specimens were stored in polyethylene bags at room conditions for the times listed. * The unprotected copper printed wiring boards oxidized rapidly after specimen preparation and were unsuitable for testing. ** Tin-lead-plating chemistry was nominally 60Sn-40Pb. *** The solder alloy used for dipping was nominally 63Sn-37Pb. **** The rosin coating is a proprietary product (Alpha 828) composed of water-white rosin and alcohol. The coating was applied immediately after solder leveling or after receiving the control specimens. † Control boards.	

Figure 3. Thickness of Solder-Leveled Coatings Versus Spray Pressure at 430°F

VIEW A

2000X

TOTAL THICKNESS RESULTING
FROM SOLDER LEVELING, IN-
CLUDING INTERMETALLIC COM-
POUND LAYER AND FREE SOLDER
(60 MICRO-INCHES).

VIEW B

2000X

FREE SOLDER LAYER REMOVED.
INTERMETALLIC COMPOUND
LAYER THICKNESS IS
30 MICRO-INCHES.

Figure 4. Total Thickness After Solder Leveling

Figure 4, View B, shows the thickness of the intermetallic compound layer on the same sample after the free-solder layer was chemically removed. Nominally, only 25 to 30 micro-inches of free solder are present on the solder-leveled surface. As determined by electron micro-probe analyses, the free-solder layer chemistry immediately adjacent to the intermetallic compound layer is high in lead content. Tin diffusion into the copper cladding has depleted the solder alloy of tin.

While the Edge Dip Solderability Test was one of the methods used in the study, it was judged as being not sensitive enough to base conclusions upon. All of the dip test samples, tested in accordance with the Edge Dip Test Method, met the criteria of 95-percent coverage.

The Pessel Spread Factor Test is not suited for directly testing the etched circuit paths of printed wiring boards because the insulating epoxy between conductor paths on the board restricts the flow of the solder and the paths are too narrow to allow the solder to spread completely. This test is suited for evaluating the solderability of basis metals.

Specimens tested with the rosin coating did not have the coating removed prior to testing. This was done because of the vendor claims that the operator can solder through the coating and because removal of the coating might invalidate the measured solderability value by also removing surface oxides from the test specimen. The rosin coating, when dried, adheres to the surface of the test specimen like varnish and a rather strong organic cleaner is needed to remove it. Possibly, larger spread factors could have been attained if the coating had been removed prior to testing.

The measured solderability is presented graphically in Figures 5 through 13. The as-plated or as-solder-dipped control surfaces (Figures 6, 7, 10 and 11) show no decrease in solderability as storage time increases. A spread factor of 97.0 was assigned to the samples on which the solder coating of the basis metal melted and allowed the solder preform to break the tension of the surface layer and mix with the already molten solder.

The error flags, given for each data point, were based on a possible ± 0.001 -inch error in the measured height used to calculate spread factors. Each data point presented is the arithmetic mean obtained from five individual test specimens tested under the same conditions and with the same test parameters.

Conclusions

- The total thickness of the solder-leveled coating is nominally 55 micro-inches, regardless of the process temperature or spray pressure.
- A spray pressure of 60 psig results in the least variation in thickness.

Text continued on page 33.

Figure 5. Solderability of Rosin-Coated, Copper Printed Wiring Board

Figure 6. Solderability of Solder-Plated Printed Wiring Board

Figure 7. Solderability of Rosin-Coated, Solder-Plated Printed Wiring Board After Storage

Figure 8. Solderability of Solder-Plated, Solder-Leveled Printed Wiring Board After Storage

Figure 9. Solderability of Solder-Plated, Solder-Leveled, and Rosin-Coated Printed Wiring Board After Storage

Figure 10. Solderability of Solder-Dipped Printed Wiring Board After Storage

Figure 11. Solderability of Rosin-Coated, Solder-Dipped Printed Wiring Board After Storage

Figure 12. Solderability of Solder-Dipped, Solder-Leveled Printed Wiring Board After Storage

Figure 13. Solderability of Solder-Dipped, Solder-Leveled, and Rosin-Coated Printed Wiring Board After Storage

- The total thickness of the resulting solder-leveled coating is comprised of several sublayers of different composition. The free-solder thickness is about 25 to 30 micro-inches.
- The solderability of a solder-leveled surface decreases with time. The decrease occurs quite rapidly during the first 2 or 3 months after solder leveling then appears to level off and asymptotically approach a value of 82 to 83 percent after 5 months. This effect is still being investigated.
- At the present time, no distinction can be made between the measured solderabilities of tin-lead plated surfaces that have been solder leveled, and solder-dipped surfaces that have been solder leveled.
- At this time, the solderability of the as-tested rosin-coated surfaces is lower than that of the uncoated surfaces.

ACCOMPLISHMENTS

The copper plate-print and etch-solder dip-solder level technique of fabricating printed wiring boards appears to be a very substantial improvement over the fabrication technique using tin-lead plating. Using the solder dip-solder level technique, very small (0.017 inch) diameter through-holes, narrow (0.008 inch) conductor widths and, close (0.008 inch) conductor spacings appear to be feasible. The limit of this technique seems to be the minimum size of a hole that can be copper plated.

FUTURE WORK

- Subsequent related work will complete solderability determinations for printed wiring boards stored for up to 12 months of natural storage time.
- Metallographic examination of solder-leveled, plated-through holes will be conducted in order to determine whether or not solder coat thickness variations exist within the hole. The solderability of plated-through holes will be measured using a float test.
- The electrical properties of typical insulating laminates will be measured after solder leveling and the results will be evaluated for any significant detrimental changes.
- The chemical composition of the proprietary solder-leveling compound will be studied to determine whether additional special cleaning procedures are needed.

A report covering this additional work should be available by March 1, 1972.

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¹B. T. Lampe, "Solderability of Thin, Fused Tin-Lead Coatings Produced by Solder Leveling," Internal Memorandum to Distribution, Bendix Corporation, Kansas City Division (July 8, 1969).

²L. Pessel, "Proposed Numerical Evaluation System for Soft Solders, Solder Fluxes, and Solderability," Symposium on Solder, STP189, American Society for Testing and Materials (1956).

DISTRIBUTION

Twelve copies of this report were printed in June, 1971, and distributed by W. A. Mulholland to selected individuals.