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Round Robin Reliability Evaluation of Small Diameter Plated-Through Holes in Printed Wiring Boards

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A technical report developed by IPC

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IPC-TR-579

Round Robin Reliability Evaluation of Small Diameter Plated Through Holes in Printed Wiring Boards

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Section 1	Introduction	1
Section 2	Conclusions and Recommendations	2
Section 3	Round Robin Test Program Details	4
Section 4	Thermal Cycle Tests and Results	6
	COM-T-CYCLE	7
	MIL-T-CYCLE	9
	APD OIL-T-SHOCK	17
	IEC OIL-T-SHOCK	21
	FLUID SAND-T-SHOCK	25
Section 5	Additional Analyses	27
	MICROSECTION ANALYSIS	27
	DIELECTRIC MATERIAL EVALUATION	30
	COPPER PLATING EVALUATION	34
Section 6	Vendor Rating and Test Correlations	36
Section 7	Plated-Through Hole Failures in Thermal Cycling: Analytical Considerations	40
Section 8	Individual Fabricator Analysis	47
Section 9	References	69
Appendix		70
A	COMPREHENSIVE DATA CHARTS (MIL-T-CYCLE)	70
B	TEST PROGRAM	76

Objective

The "Round Robin Reliability Evaluation of Small Diameter Plated-Through Holes (PTH) in Printed Wiring Boards" had the following objectives:

- Evaluate the performance of small diameter PTHs under controlled environmental conditions.
- Evaluate the influence of the thickness and quality of deposited copper on PTH performance.
- Determine the impact of varying PTH aspect ratios.
- Collect data on the influence of product design or manufacturing methods.
- Determine if test results from different military and industrial thermal cycle and/ or thermal shock procedures can be correlated.

Background

Current electronic circuit packaging designs demand that the printed wiring board provide increasingly complex interconnections. This density increase is required because integrated circuits are more complex and perform more numerous functions than ever before. Increases in surface mount applications also require increased density of the circuitry. By and large, PWB designers or manufacturers select PTH diameters based on component lead assembly requirements or, in the case of vias, upon available space for conductor routing or board real estate. The risk associated with smaller diameter holes is often ignored. Since through-hole dual-in-line (DIP) devices use relatively large diameter holes, this indiscriminate hole selection is not a problem. However, indications are that smaller diameter PTHs may require caution.

In September 1984, the IPC published IPC-TR-578, "Leading Edge Manufacturing Technology Report." As part of the extensive testing performed in this round robin, a thermal cycle test was used to determine PTH cyclic performance. Small diameter PTHs showed unexpectedly poor performance. Since this report was not aimed at small hole evaluation, extensive failure mode analysis was not possible at that time, and

the PWB industry was left forewarned of a potential problem.

In April of 1986, the Technical Activities Executive Committee recommended to the IPC Board of Directors to study small PTHs. The Directors approved and a task force was selected to evaluate the reliability of small diameter PTHs. For the purpose of this program, small diameter PTHs are defined as drilled hole diameters of 0.020" or less.

This new round robin program concentrated solely on small holes and the effects of design, construction, and metallization. The following are the principal features of this round robin evaluation:

- Participation was limited to those fabricators who have experience and demonstrated competence in producing small holes. This restriction was made to prevent immature, prototype, or laboratory scale contributions which might distort the data base.
- Four drilled hole diameters were chosen for review: 0.020", 0.016", 0.0135", and 0.010".
- Two different deposited copper thicknesses were evaluated: 0.00075" (thin), and 0.00125 (normal)
- The PTHs were tested in a bare copper state. Additional specimens were tested with fused solder finishes in order to determine if solder obscures PTH failures.
- Substrate material was essentially limited to epoxy glass (FR-4), since the fabricators participating in the program had ample experience in processing this material. However, polyimide was allowed for selected configurations.

- Base material thicknesses of 0.030", 0.060", and 0.090" were employed, which yielded aspect ratios from 1.5:1 to 9:1.
- Construction was double-sided (DSR) and multilayer (MLB). No restrictions were placed on the manufacturing processes except that they be representative of current production methods. DSR and MLB samples were fabricated as pair sets to assure process consistency and avoid differences due to production timing intervals.
- Double-sided boards with a multilayer construction (laminated with prepreg without internal circuitry) were also a part of the program. These two-sided multilayer boards (2SML) were included in order to determine the effects of lamination and the absence of internal circuitry, in comparison with multilayer boards with internal circuitry.
- The majority of tested PWBs were preconditioned prior to test by a simulated assembly process designed to duplicate multiple thermal exposures typically seen in the manufacturing process. The assembly process consisted of a bake of +250°F (121°C) for three hours followed by five cycles of a vapor phase heating at +425°F (218°C) at a conveyor rate of 54 inches/minute, for a boiling sump exposure of 70 seconds.
- Each fabricator was requested to submit detailed information on important processing functions, materials and chemical information.
- The five major test cycles chosen for thermal cycle testing are as listed in Table 1.

Table 1 Conditions of Thermal Cycling Tests

Test	Temperature Range	Duration
MIL-T-CYCLE	-65°C to +125°C	400 cycles
COM-T-CYCLE	0°C to +100°C	1000 cycles
IEC OIL-T-SHOCK	+25°C to +260°C	10 & 30 cycles
APD OIL-T-SHOCK	-35°C to +125°C	400 cycles
FLUID SAND-T-SHOCK	+25°C to +260°C	30 cycles

Section 2

Conclusions and Recommendations

Conclusions

The five principal objectives of this Round Robin Program have essentially been met. Approximately 200,000 PTHs were tested covering primarily electroplated but also some electroless technology. The quality of submissions to the program was representative of the PWB industry at large and provided a useful data base without undue anomalies. With this in mind, the task force offers the following summary of conclusions and recommendations derived from the current Round Robin Test Program.

1. The task force feels that the participants and processes employed for PTH manufacture in this program correctly mirrors the profile of contemporary PWB industry production.
2. Small diameter PTHs when employed with typical PWB dielectrics (epoxyglass) and metallization techniques will typically fail within 400 cycles of a MIL-T-CYCLE test.
3. The task force rated the participants with respect to their ability to meet various thermal cyclic requirements. Only 24% of the fabricators could pass more than 300 MIL-T-CYCLES. Approximately 38% failed between 100-300 cycles, 33% failed at less than 100 cycles, and 5% were rated totally inept.
4. The round robin program determined that the reliability of the PTH is strongly influenced by the following variables: hole diameter, thickness of board, thickness of copper, and copper metallurgical quality (ductility & tensile strength).
5. Reliability decreases as the PTH diameter decreases.
6. PTH reliability decreases as the thickness of the PWB increases.
7. Aspect ratios of three or lower showed no failures in the test durations used (Table 1). However, the failure data show that reliability decreases with increasing aspect ratios larger than 3.
8. PTHs with thin copper, whether plated thin or a result of localized plating deficiencies, have a markedly higher failure rate.
9. PTHs with thicker copper that is uniformly deposited demonstrate better thermal cycle performance.
10. There were few failures in 0.030" thick PWB regardless of plating process and PTH diameter.
11. The full-build electroless copper fabricated holes performed extremely well in all board constructions submitted. It should be noted that there were no electroless submissions in the 0.090" category.
12. There does not appear to be any specific relationship between major acid copper formations plated from the various formulations used and PTH reliability.
13. PTH quality is the principal influence on reliability.
14. The task force found that an analytical PTH-Quality Index (see Section 7) can successfully quantify the PTH quality and its impact on PTH reliability.
15. The copper plating process window narrows as the PTH aspect ratio increases. For example; high aspect-ratio PTHs (9:1) of marginal quality reach 1% failure hazard levels at about 75, 200 and 450 cycles in respective use environments of 120, 80 and 6°C temperature excursions (based on the analytical model in Section 7).
16. For high-reliability applications in severe use environments, standard electrolytic plating processes become inadequate for higher PTH aspect ratios, even with optimum process controls.
17. Higher T_g values for epoxy-glass laminates appear to increase thermal cycle performance capability.
18. Differences in CTE and percent resin showed no effect on hole reliability.
19. Cross sectional analysis reveals that most failures occur at the resin rich regions.
20. Thermal cycle reliability cannot be accurately predicted by cross sectional analysis.
21. Solder coatings do not significantly aid reliability.
22. DSR construction yields higher cycles to failure than MLB construction.
23. Functional or nonfunctional inner-layer lands appear to improve reliability.
24. The MIL-T-CYCLE test run for 400 cycles provides a highly discriminating test for detecting potential PTH hole reliability problems. It can reveal both infant mortality failures as well as wearout failures, for aspect ratios above 3.
25. The APD OIL-T-SHOCK test provides data which correlate well with the MIL-T-CYCLE test results, and does so in one quarter of the time.
26. The COM-T-CYCLE test, which was the test performed that was most representative of actual use environments, revealed only failures in very low quality boards in 1000 cycles. It would need to be carried to about 5000 cycles to provide the same discrimination as the MIL-T-CYCLE test.
27. The IEC OIL-T-SHOCK test for 10 cycles does not discriminate reliability differences between various PTH diameters.
28. The IEC OIL-T-SHOCK test does not simulate fatigue failure and is more characteristic of a thermal stress test. There was poor correlation with MIL-T-CYCLE results. Some samples which failed early in the MIL-T-CYCLE or APD OIL-T-SHOCK passed the IEC OIL-T-SHOCK cycle.
29. The FLUID SAND-T-SHOCK test run for 30 cycles provides data which correlate with the MIL-T-CYCLE test results. It was expected that data from the FLUIDS-AND-T-SHOCK and IEC OIL-T-SHOCK would correlate because of the identical thermal shock conditions (ΔT). This correlation was not evident in the data collected.

30. The majority of failures observed during MIL-T-CYCLE tests were recorded during temperature transitions rather than at the low or high temperature dwells.
 31. Preconditioning the PWBs by subjecting them to five vapor phase cycles, which simulated assembly temperature extremes, damaged the PTHs, and reduced reliability.
 32. The rate of change in ohmic resistance under the cyclic stress of the APD OIL-T-SHOCK test varied widely for different hole diameters. The 0.010" holes require approximately 75 cycles to increase resistance 50%, but a 0.020" hole requires approximately 400 cycles to reach the same resistance change.
 33. The task force felt that no meaningful conclusions could be drawn from the polyimide PWB test data due to the insufficient submittal of polyimide PWBs for test.
- insure plating processes are capable of producing reliable small diameter PTHs.
 7. For IPC specifications, a preliminary proposal is that Class 1 products should survive 50 cycles, for Class 2 100 cycles and for Class 3 300 cycles of the APD-OIL-T-SHOCK test. The tests should be preceded by appropriate preconditioning simulations of assembly and rework processes.
 8. The IPC should encourage development of a method with which copper plating samples representative of copper plating in the PTH can be obtained and properly evaluated.
 9. The IPC should encourage the development of copper plating processes giving higher strength/higher ductility deposits in PTH barrels needed for high aspect-ratio high-reliability PTHs.

Recommendations

1. The IPC should incorporate in appropriate specifications a thermal cycle requirement for designs containing small diameter PTHs.
2. The thermal cycle test showing the most promise is the APD OIL-T-SHOCK, which yields results equivalent to the longer MIL-T-CYCLE in one quarter of the time. The temperature cycle suggested is -35° to +125°C.
3. The FLUID SAND-T-SHOCK also shows promise as a possible MIL-T-CYCLE replacement. However, since only one PTH diameter was evaluated, further work is recommended to determine the capability of this test to discriminate between PTHs of different diameters.
4. Board or panel test coupons should always contain the smallest diameter hole specified.
5. When vendor, process or material changes are contemplated for small PTH diameter designs, a thermal cycle test should be employed to reveal any effects on PTH reliability.
6. Process controls employed for copper metal deposition should be verified with thermal cycle testing to



Section 3

Round Robin Test Program Details

Usually, large scale IPC round robin programs take 3-4 years from conception to publication of data. Due to the importance of small diameter PTH reliability, the task force agreed to expedite the entire evaluation period such that publication would occur by September 1988. The program was conceived in April 1986, and by August a completed test plan was available. This is included in the Appendix. By September of 1986, an excellent expression of participation was received from the IPC membership. Art masters were distributed in September and by January 1987, the bulk of

the submitted samples were inspected by the task force. By April 1987, essentially all sample submissions were in full test. The task force rejected seven fabricator submissions for noncompliance with test plan instructions. In September 1987, the testing was completed.

The test program included submissions from 16 different companies representing the United States, Japan, Taiwan, China, Hong Kong and Italy.

Three variations of metallization technology were employed to fabricate the PTHs:

- Acid copper—includes various vendor's acid sulfate copper
- Full build electroless copper—includes semi-additive and fully additive processes
- Acid copper no pre-electroless—acid sulfate copper with a proprietary non-electroless base

Test Pattern and Boards in the Round Robin Program

The test pattern developed for this program is shown in Figure 1. It consists of a serpentine pattern which contains 100 holes in each net. There are eight nets to each specimen and they are all connected to a common ground. Each net on either side of the ground path was provided with a single hole size i.e., S-1 had 0.010" holes, S-2 – 0.135", S-3 – 0.016", and S-4 – 0.020" holes. The other four nets were identical so that a left hand/right hand pattern existed. The "X" and "Y" patterns were employed for cross sectioning, and the "Z" pattern was employed for registration review. There were eight of these patterns to a panel, and the panel size was 14" x 16".

Participants in the program were requested to submit six panels per set. Each set consisted of three panels with normal copper thickness and three panels with thin copper. If the fabricator normally supplies solder over copper, an additional two panels were requested: one with solder over thin copper and one with solder over normal copper. Fabricators did not have to submit all requested board constructions but some fabricators did submit multiple entries.

Of the 103 sets submitted for evaluation, the breakdown by category of fabrication is listed in Table 2.

About the Testing Companies

The Task Force is indebted to the nine companies listed below who performed the comprehensive detailed testing required by this program.

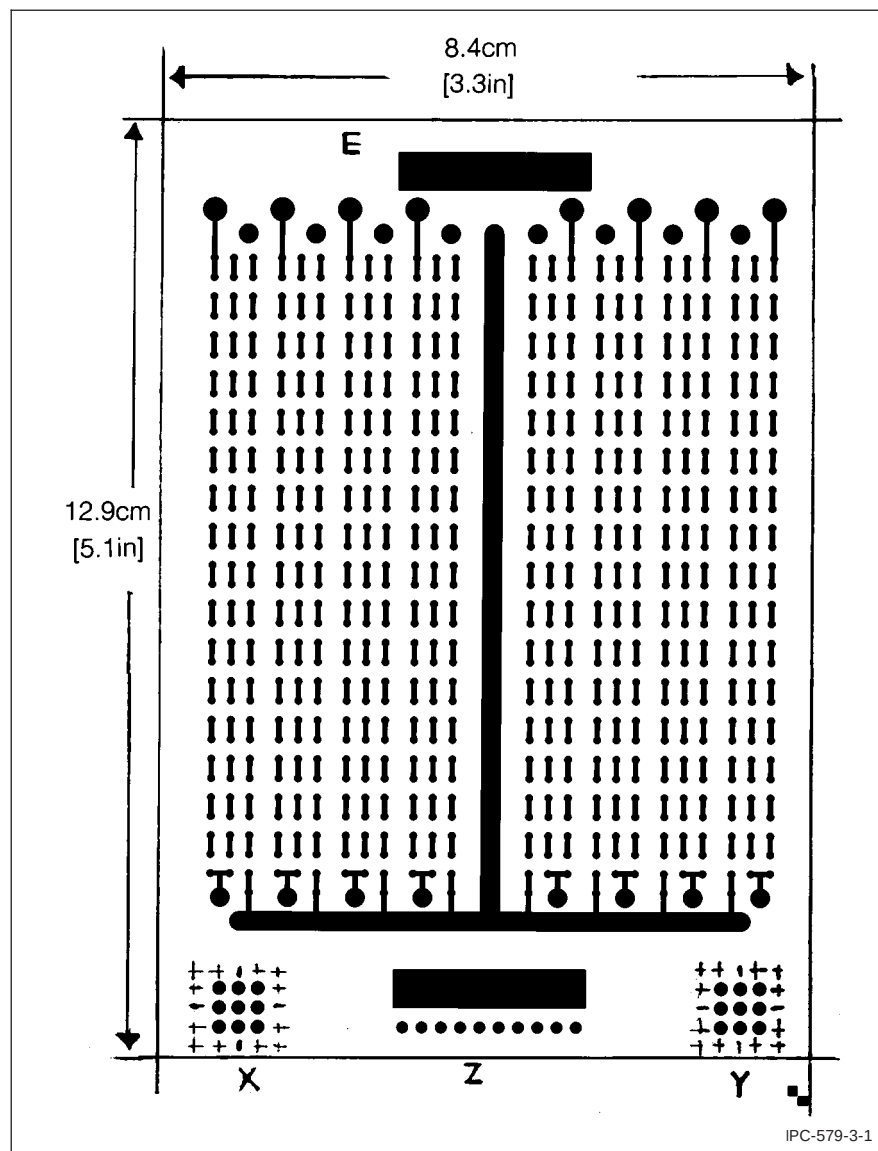


Figure 1 Test Pattern

Table 2 Board Constructions, Sets Tested and Report Nomenclature

Sets Under Test	Board Thickness (Inches)	Board Construction	Report Nomenclature
7	0.030	DSR	030 DSR
8	0.030	2-Sided ML6	030 2SML
24	0.060	DSR	060 DSR
12	0.060	2-Sided ML6	060 2SML
19	0.060	4-Layer MLB	060 4LML
12	0.060	10-Layer MLB	060 10LML
10	0.090	4-Layer M LB	090 4LML
8	0.090	10-Layer MLB	090 10LML
3	0.090	10-Layer MLB (Polyimide)	090 10LMLP

Additive Products Division
AT&T
GE
Ferranti
IBM
Martin Marietta
PCK Technology
Philips MBLE
Texas Instruments

Hundreds of samples were examined, many thousands of readings taken, and approximately 200,000 PTHs were tested.

About the Task Force

The individuals listed below comprised the IPC task force for evaluating the reliability of small diameter PTHs. They were selected because of their acknowledged expertise. The IPC and its member companies wish to thank these individuals whose organization, knowledge and dedication made this report possible.

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Section 4

Thermal Cycle Tests and Results

Introduction

The task force selected PTH thermal cycle tests which are commonly used both domestically and internationally. The IEC OIL-T-SHOCK and FLUID SAND-T-SHOCK are standard tests in Europe and the Far East. In America, the APD OIL-T-SHOCK and FLUID SAND-T-SHOCK are employed. The MIL-T-CYCLE is widely used, but with variations in test duration and dwell times. The COM-T-CYCLE was devised by the task force to simulate general product use conditions.

The task force selected tests which would induce either fatigue or over stress failure of the PTHs. The task force members tailored the test conditions so that the tests would neither be too benign nor require extraordinary duration, but would probably induce fatigue failure. Each test program is described on the following pages.

Boxplots

Some of the test results are graphically presented in boxplots, referred to as "charts" in this report. Following is an explanation of boxplots:

Boxplots are simple graphic representations of subgroups of a numeric variable. Boxplots are especially useful when comparing many subgroups (See Figure 2).

The vertical ends of the boxes are the 25th and 75th percentile points, and the cross in the middle is the median (the 50th percentile). The vertical lines, or "whiskers," are drawn to the largest and smallest values that are probably not outliers. Likely outliers are represented as individual scatter symbols. The relative widths of the boxplots are proportional to the square roots of the sample sizes. The broader the boxplot, the more data within a given plot.

For a given group, the "whiskers" are calculated as follows: The interquartile range, which is the length of the box, is multiplied by 1.50. This is added to the third quartile, this is, to the top of the box. The upper whisker is drawn to the largest value less than this quantity. The lower whisker is drawn similarly; it is drawn to the smallest value greater than the first quartile minus 1.5 times the interquartile range. Note that this method always draws the ends of the whiskers to actual data points.

By option, the boxplots may be drawn with notches. The narrow part of the

notch is the median, and the vertical extent of the notch is the 95 percent confidence interval for the median. This confidence is formed nonparametrically; its validity does not depend on assuming the underlying distribution is normally distributed, or any similar assumption.

Boxplots are used in Charts 1-48 to show the results of the MIL-T-CYCLE test and the effects of various parameters, such as hole diameter on PTH performance.

Those charts and figures which are organized by vendor always follow the same order; they show the same vendor in the same relative position. The vendors have been ordered to be best-to-worst from left to right in all graphical representations.

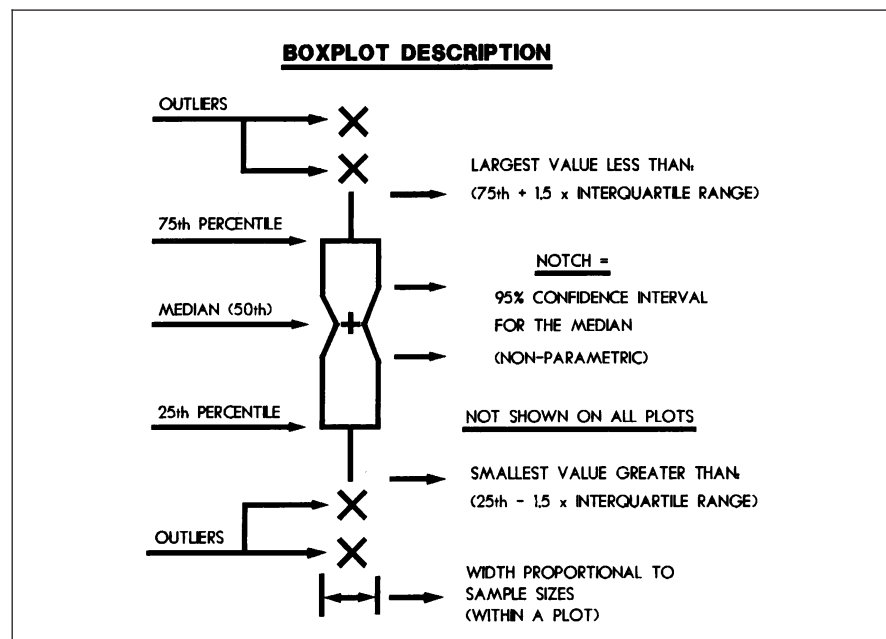


Figure 2 Boxplot Description

Objective

To determine the integrity and general reliability of various diameter PTHs in PWBs by monitoring the PTH electrical continuity on test PWBs subjected to 1000 cycles of 0°C to + 100°C temperature cycling; and to determine whether hole diameter, hole plating thickness, or PWB thickness affect PTH integrity and reliability. This test exposure was the most representative of actual service environments of all thermal tests run in this program.

Test Procedure

Labelled PWBs were received from IPC and assembled for electrical continuity monitoring by soldering 26 AWG coated copper wires to each board for connection to a Fluke 224°C Datalogger and 10 milliamp current source. All eighty-six test boards were simultaneously subjected to 0°C to + 100°C temperature cycling in a Thermotron Model #S-1.2 Mini Max temperature cycling oven. A thermocouple placed in the air at the back of the oven monitored the oven air temperature. The actual temperature profile obtained on the surface of a board in the center of the oven is shown in Figure 3. The test boards were held at 0°C ($\pm 2^\circ\text{C}$) for 40-42 minutes and at + 100°C ($\pm 2^\circ\text{C}$) for 20-23 minutes with a ramp profile of approximately 3.4°C per minute between each temperature extreme.

Initial resistance values at room temperature, 0°C, and +100°C for each of the eight test nets on each test board were recorded. No soldering rework or PWB defect verification and replacement was performed at this point since the large quantity of PWBs and wires in the cycling oven prohibited easy access to any single PWB and scheduled oven use could not be delayed. Resistance measurements on the eight test nets of each board were made every 50 cycles at 0°C and +100°C through 1000 cycles over a period of 93 days. If the test net resistance increased four fold over the initial room temperature resistance measurement, this was considered a PWB test net failure.

Test Results

Fifteen boards out of the 86 boards tested had a total of 33 test net failures. Five of these fifteen boards had 12 test net failures immediately following lead attachment at initial room temperature resistance measurements. One failed at initial low temperature dwell. Four more failures occurred on two boards at the first cycle high temperature dwell. The remaining 16 failures on six boards occurred during testing in the range from 50 to 500 cycles. The other 315 test nets maintained circuit continuity with little or no resistance change throughout the testing. A summary of all test net failure results is shown in Table 3.

Conclusions

Eight of the initial net opens resulted from holes not-drilled; two from damage to the PWB. While the possibility of test lead attachment problems cannot be ruled out for some of the seven remaining initial test net failures, the majority of these failures are likely attributable to the

5 vapor phase conditioning cycles and/or infant mortality. All the boards with test net failures after the first cycle were made by vendors who were rated as marginal or poor by MIL-T-CYCLE performance (see Sections 6 and 7).

Analyses in Section 7 indicate that the 0°C to + 100°C COM-T-CYCLE is not severe and produces failures within 1000 cycles only on very poor quality PTHs. In Section 7 it is estimated that the COM-T-CYCLE test needs to be carried to 5000 cycles to obtain the same discriminating power as the MIL-T-CYCLE test.

Objective

To determine the integrity and general reliability of small diameter PTHs in PWBs by monitoring the PTH electrical continuity for 400 cycles over a temperature range of -65°C to +125°C; and to determine whether hole diameter, hole plating thickness and PWB thickness affect PTH integrity and reliability.

Table 3 COM-T-CYCLE Test Net Failures

Board Construction	Hole Diameter	Cycles To First Failure on Test Net	Vendor Rating
.060 4LML	.020"	0	Good
.060 2SML	.010"	0	Good
.060 10LML	.010" .0135"	0 received 0 damaged	Marginal
.090 4LML	.010"	4 x 0 not drilled	Good
.090 10LML	.010"	4 x 0 not drilled	Good
.060 DSR	.0160"	1/2 low temp. open	Good
.030 DSR	.010"	1 high temp. open	Superior
.090 4LML	.0135" .0160" .020"	1 high temp. open 1 & 1 high temp. open 500 & 550	Poor
.090 4LML	.010" .010"	50 & 50 300 & 300	Marginal
.060 10LML	.010"	50 & 150	Marginal
.060 DSR	.010" .0135"	50 & 50 500	Marginal
.060 2SML	.010" .0135"	50 & 50 50	Marginal
.060 4LML	.010"	50 & 100	Marginal

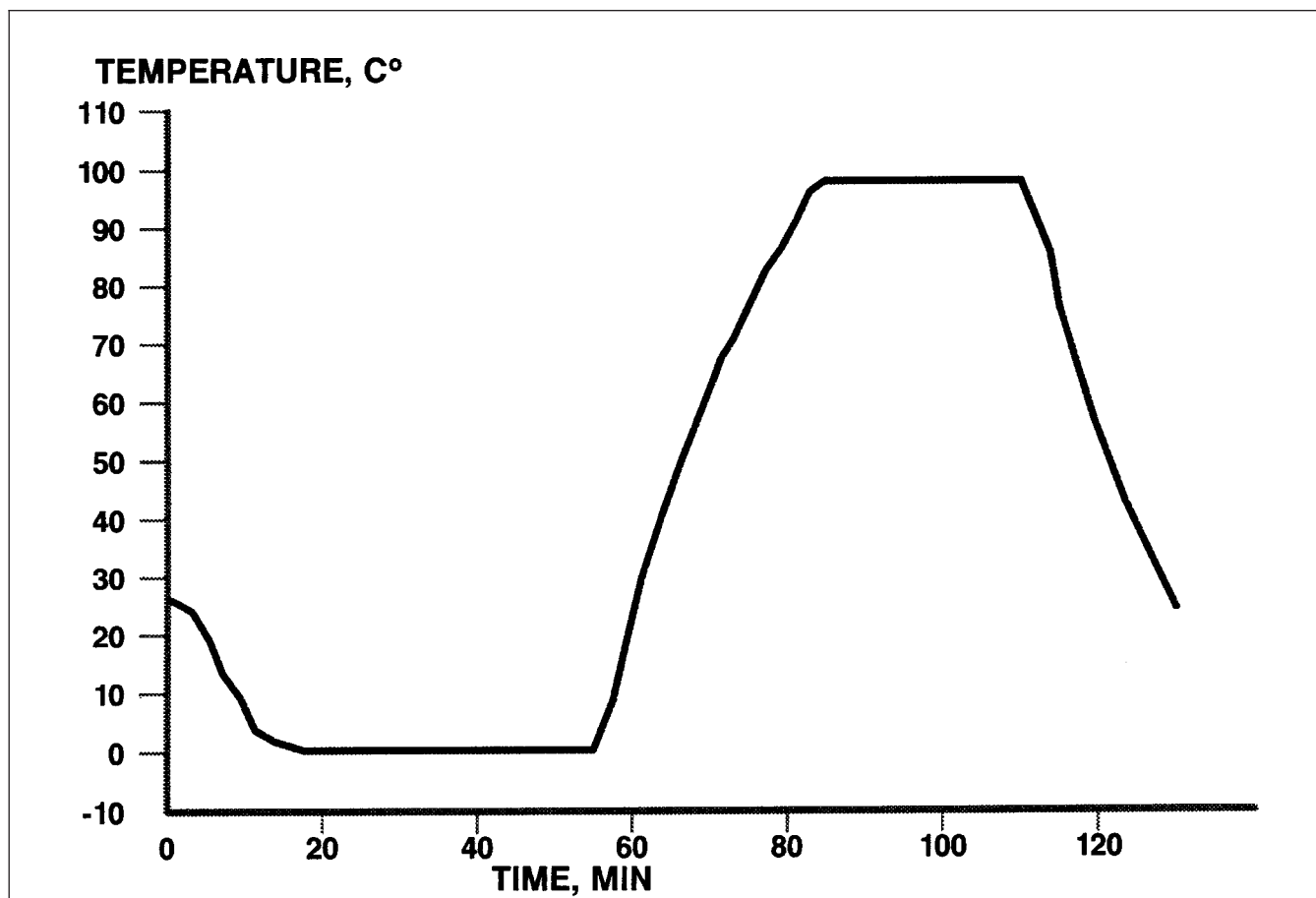


Figure 3 COM-T-CYCLE temperature profile

Test Procedure

Testing was conducted at two different locations. There seemed to be no significant difference in test procedures or results from the two locations; therefore, the results reported here are the average of the data obtained at both locations.

The test boards were placed in an air circulating temperature chamber manufactured by Thermotron. Thermocouples were used to monitor the chamber air temperature at the back of the chamber, and the actual board surface temperature in the middle of the chamber. The board surface temperature profile obtained is shown in Figure 4. The chamber was set for a 30 minute dwell at the two temperature extremes, and a 38 minute (5°C per minute) transfer time between temperature extremes. Under these conditions, the actual PWB's surface temperature was at –65°C and at +125°C ($\pm 2^\circ\text{C}$) for approximately 20 to 22 minutes each. The total length of the test was 800 hours, or about 33 days.

Each net (100 daisy chained PTHs) was connected individually to a data monitoring system that measured electrical resistance. Initial resistance values at room temperature, –65°C, and +125°C for each of the eight test nets on each PWB were recorded. All the test nets were electronically measured every 30 seconds for resistance changes. If the test net resistance increased fivefold over the initial resistance measurements, this was considered a failure. When a failure was indicated, the failed test board was removed from the temperature chamber at room temperature within 48 hours from the time of failure indication. The failed net was hand-probed with a multi-meter; the defect was identified, and its location marked. Then, the test board was returned to the temperature chamber for the duration of the test.

In compiling the test results, the first PTH failures in a net were considered the failure for that net.

Test Results

- All 0.030 inch DSR test boards passed 400 cycles.

- Samples of failed test boards examined after the conclusion of the test showed numerous PTH failures within a net.
- The 0.010 inch diameter PTHs failed earlier and more frequently than any other diameter PTH.
- Most PTH failures (62%) occurred during the temperature transition (see Figure 5).
- Three times more PTH failures occurred at high dwell temperature (28%) than at low dwell temperature (10%) (see Figure 5).
- Charts 1-11 are data summary box-plot analyses performed for the MIL-T-CYCLE test. All the basic data charts representing raw data, plotted on a per vendor basis are located in Appendix A and are provided for reader information.

Conclusions

- As Chart No. 1 shows, PTH reliability decreases as PWB thickness increases.
- PTH reliability increases with increasing PTH diameter (see Chart No. 2).
- As might be expected from the two previous conclusions, test data shows that PTH reliability decreases with increasing aspect ratio, as evident in Chart No. 3. This effect is even more clear in Chart No. 4, which shows reliability vs. aspect ratio for 0.060 inch thick panels only.
- PTHs with normal copper thickness passed a much greater number of cycles than holes with thin copper (see Chart No. 5).
- The data from the 0.060 inch thick PWBs indicates that thermal conditioning, which simulates assembly temperature extremes, decreases PTH performance (see Chart No. 6). However, the effect of conditioning was less significant for 0.090 inch thick PWBs, perhaps because the deleterious effect of board thickness was much greater than the effects of conditioning (see Chart No. 7).
- Chart No. 6 and No. 7 indicate that for both the 0.060 inch and 0.090 inch thick PWBs, fused solder on noncon-

ditioned boards does not significantly improve PTH performance.

- Chart No. 8 shows the combined effects of both PWB thickness and hole diameter on PTH performance. The results are consistent with earlier conclusions; increasing PWB thickness decreases PTH life and decreasing hole diameter decreases PTH life.
- Evidence indicates that the PTHs in DSR boards are more reliable than those in MLBs, all other variables being equal. This effect is clearly shown in Chart No. 9, which shows PTH performance for 0.030 inch thick PWBs, and in Chart No. 10, which shows PTH performance for 0.060 inch thick PWBs.
- Charts 10 and 11 indicate that internal lands improve performance of multi-layer boards. However, the increase from none to two internal lands shows a significantly larger benefit than the increase from two to eight internal lands.
- 0.030 inch thick PWBs did well regardless of the hole diameter.

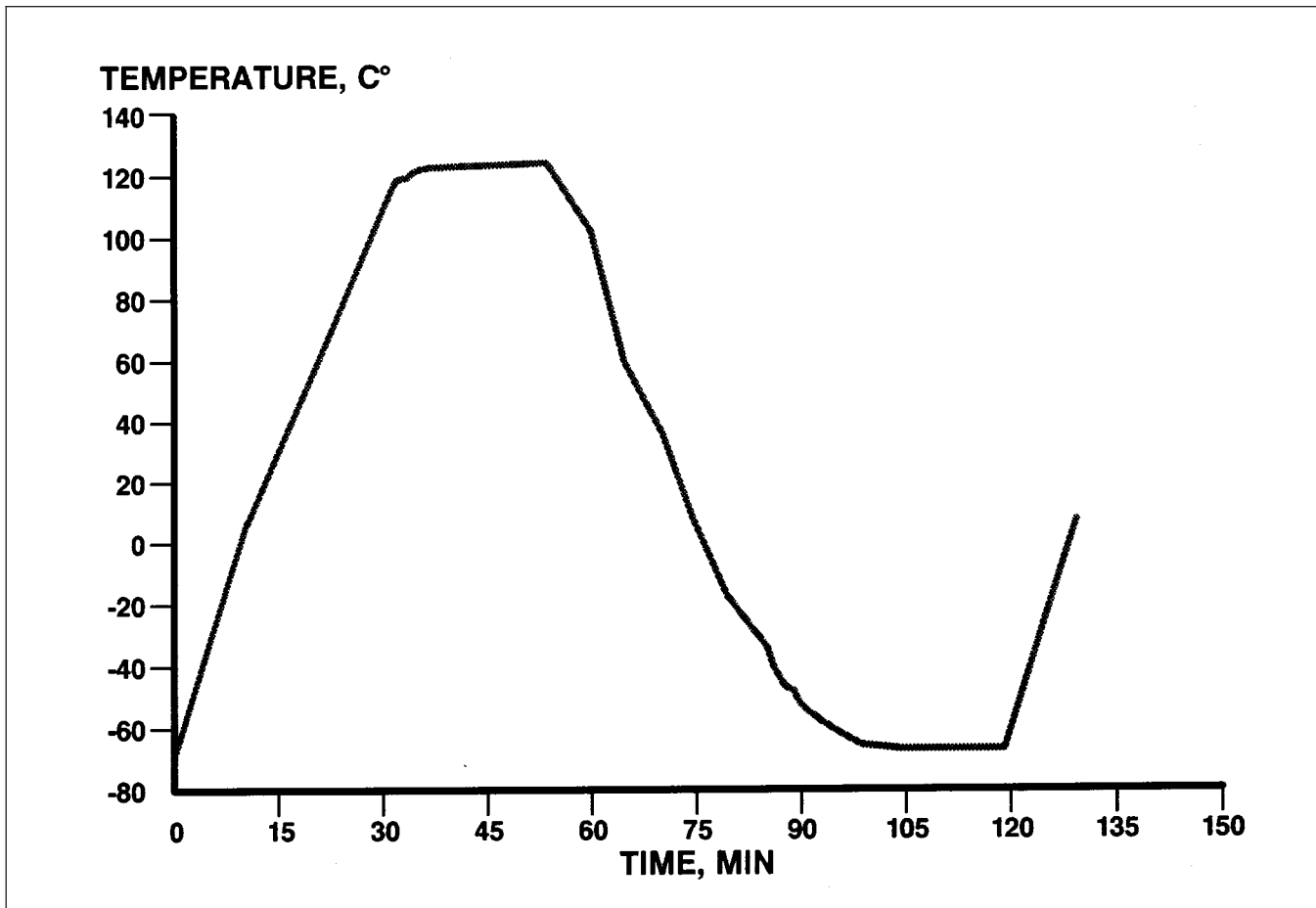


Figure 4 Board surface temperature cycle profile measured on PWB during MIL-T-CYCLE

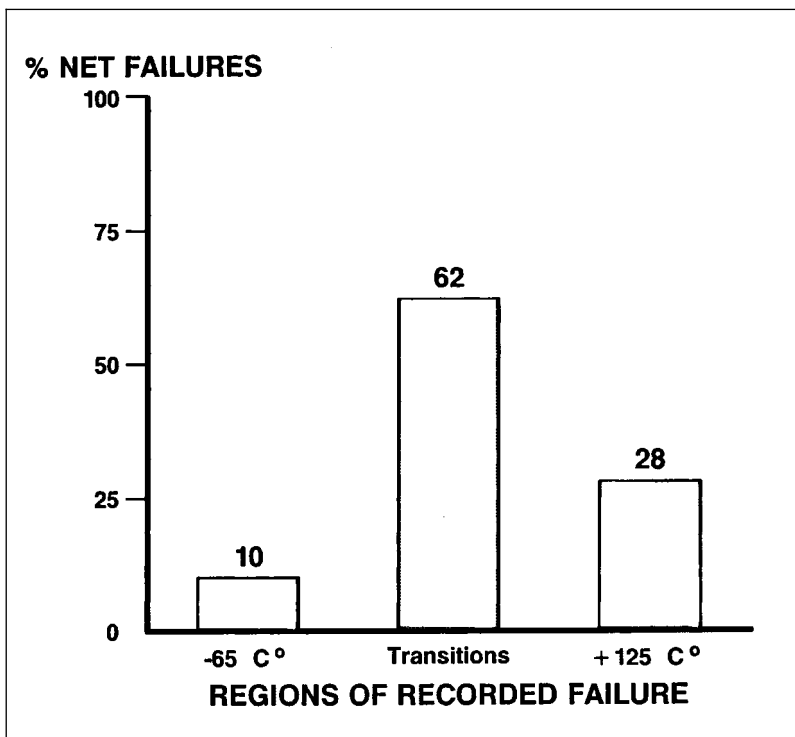


Figure 5 Percent failed nets relative to temperature profile position

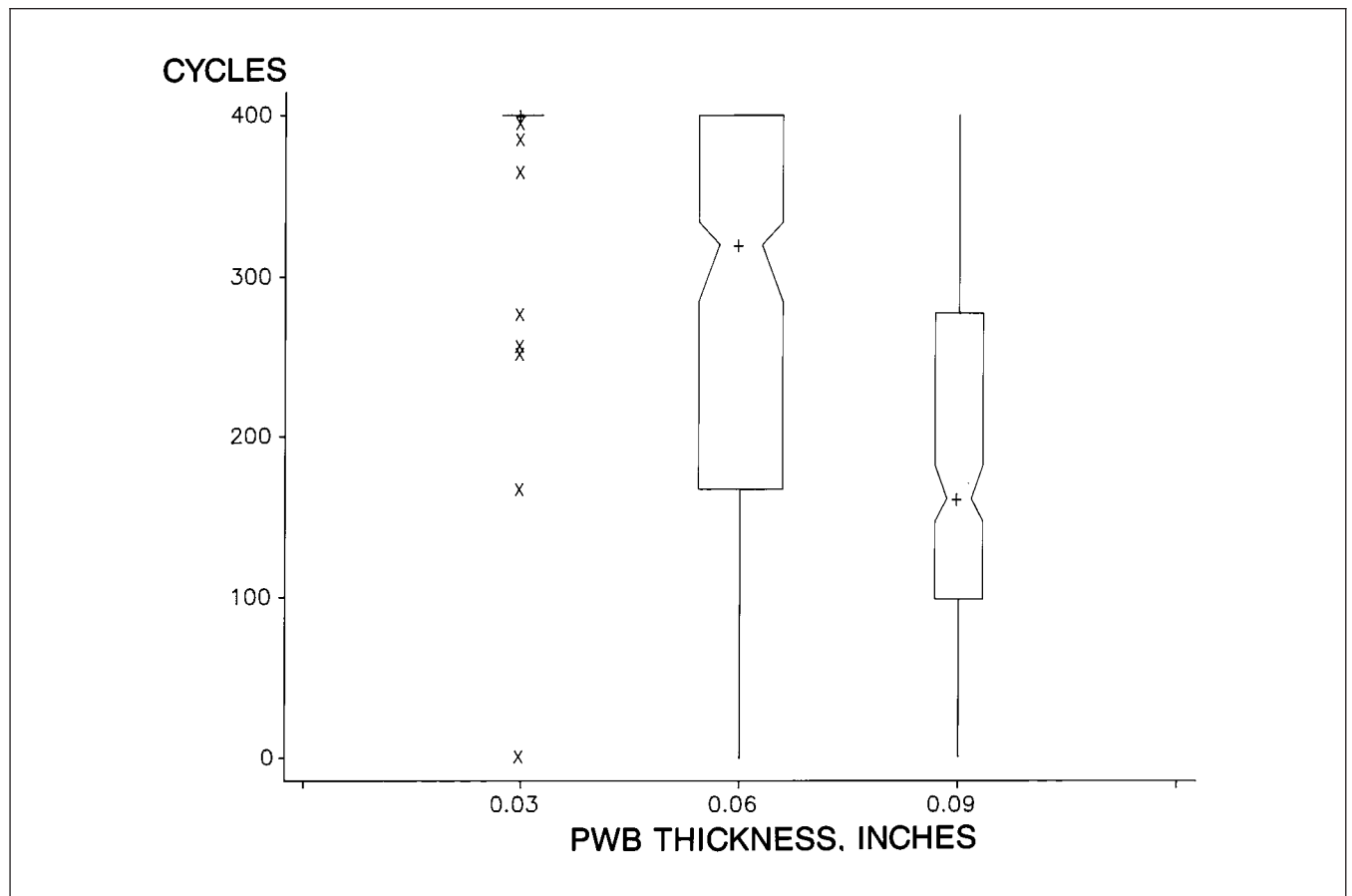


Chart 1 Cycles to failure vs. PWB thickness for MIL-T-CYCLE (all PTH diameters & board constructions)

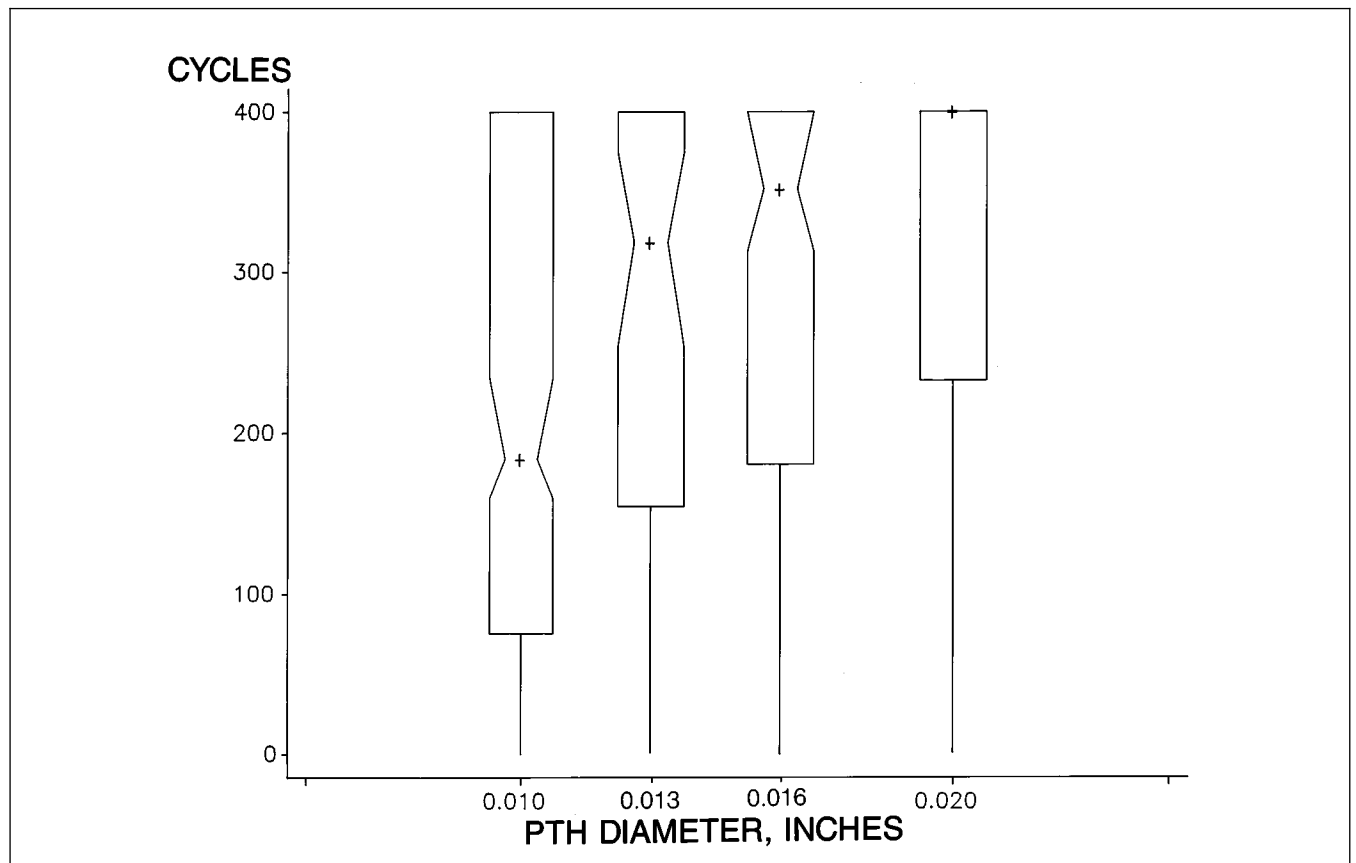


Chart 2 Cycles to failure vs. hole diameter for MIL-T-CYCLE (all PWB thicknesses & constructions)

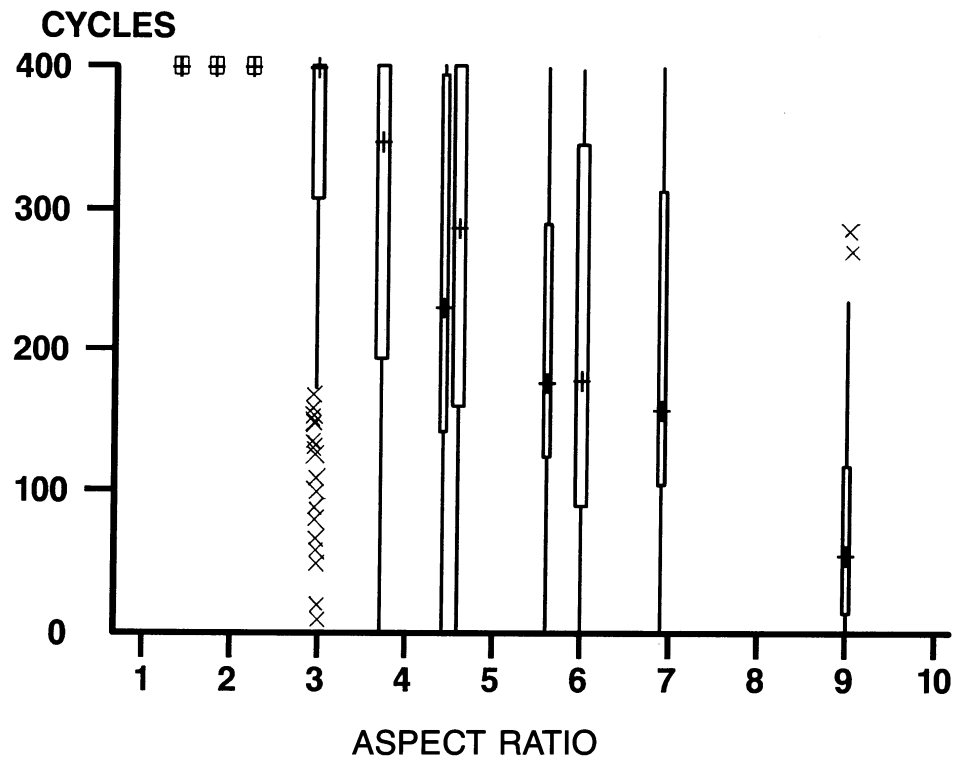


Chart 3 Cycles to failure vs. aspect ratio for MIL-T-CYCLE (all PTH diameters, PWB thicknesses & board constructions)

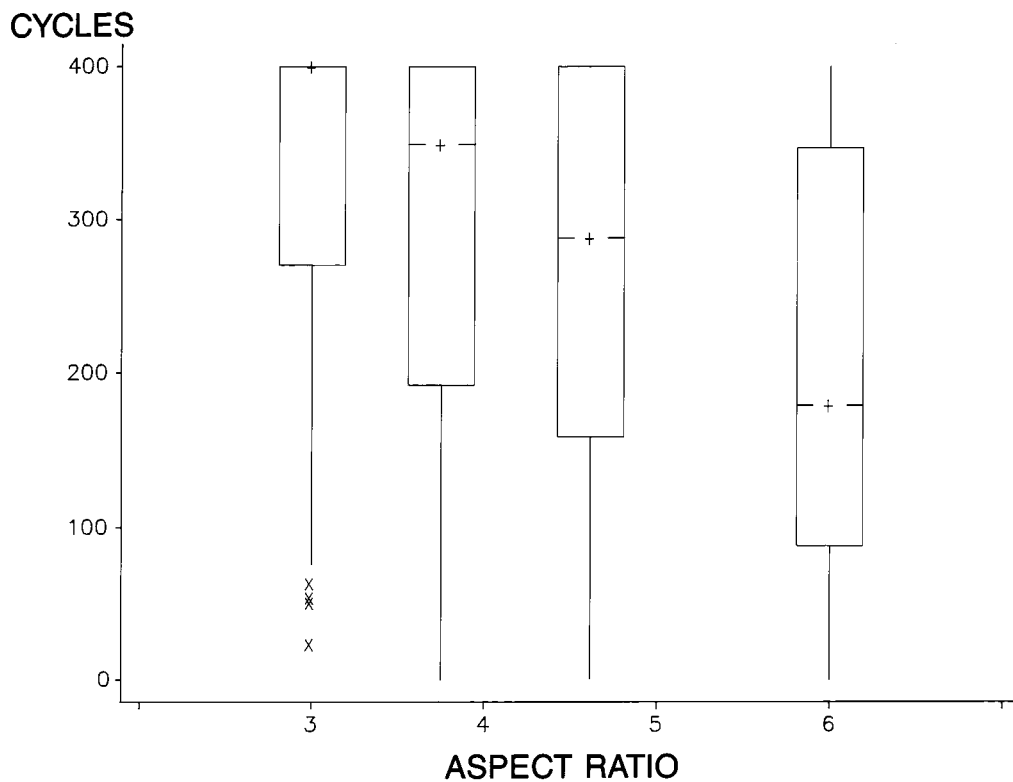


Chart 4 Cycles to failure vs. aspect ratio for 0.060" thick panels for MIL-T-CYCLE (all PTH diameters & board constructions)

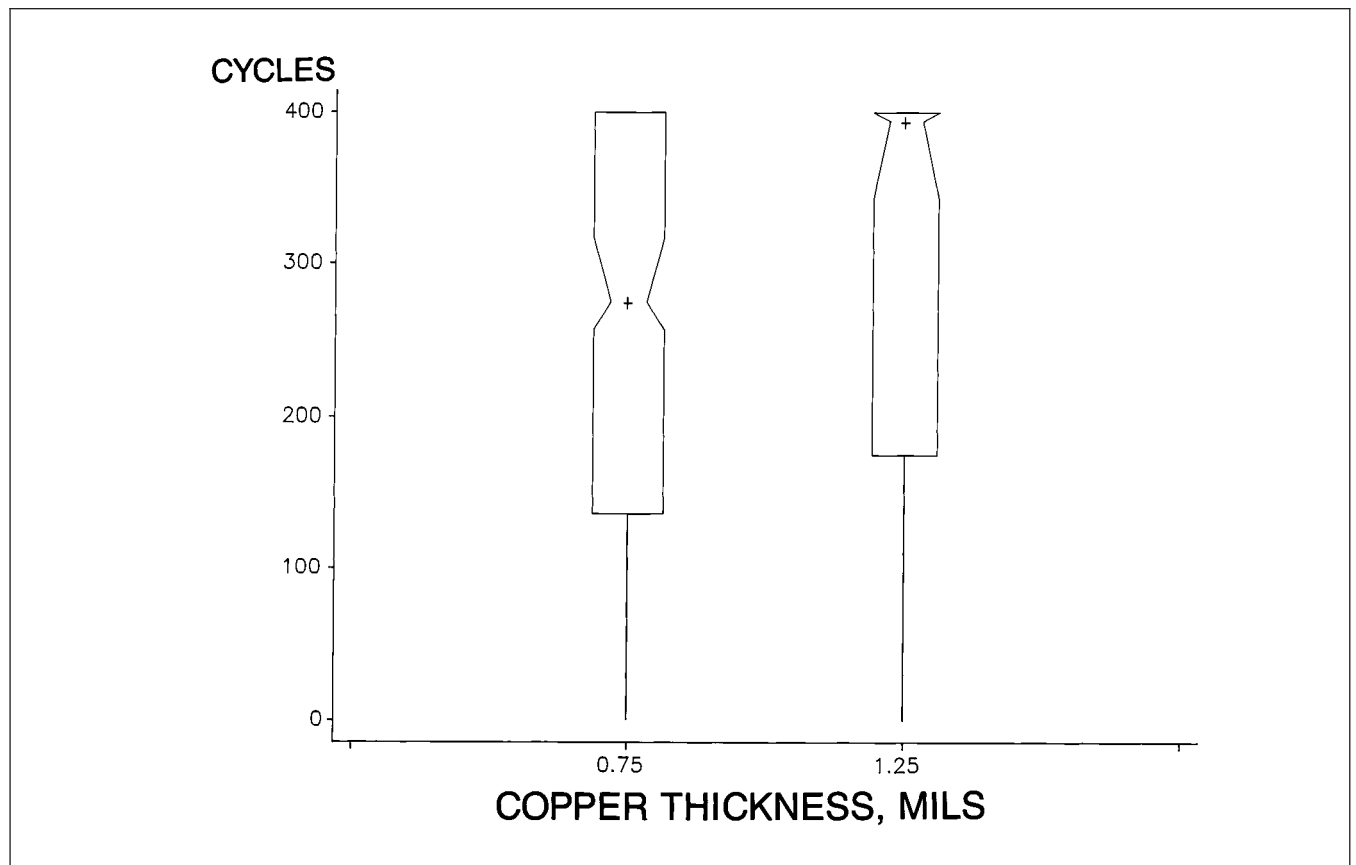


Chart 5 Cycles to failure vs. design copper thickness for MIL-T-CYCLE (all PTH diameters, PWB thicknesses & board constructions)

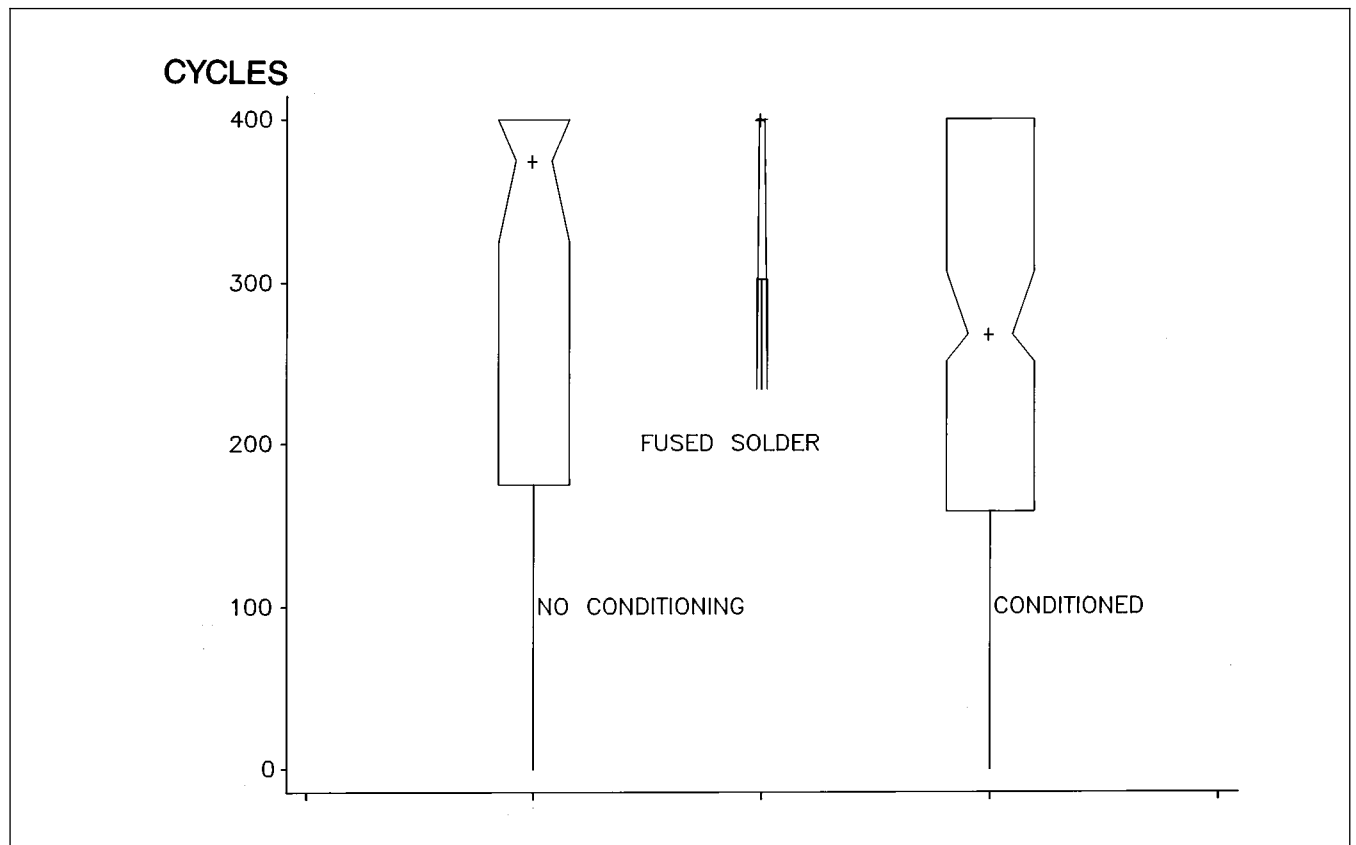


Chart 6 Cycles to failure for .060 thick PWBs vs. conditioning for MIL-T-CYCLE (all hole diameters)

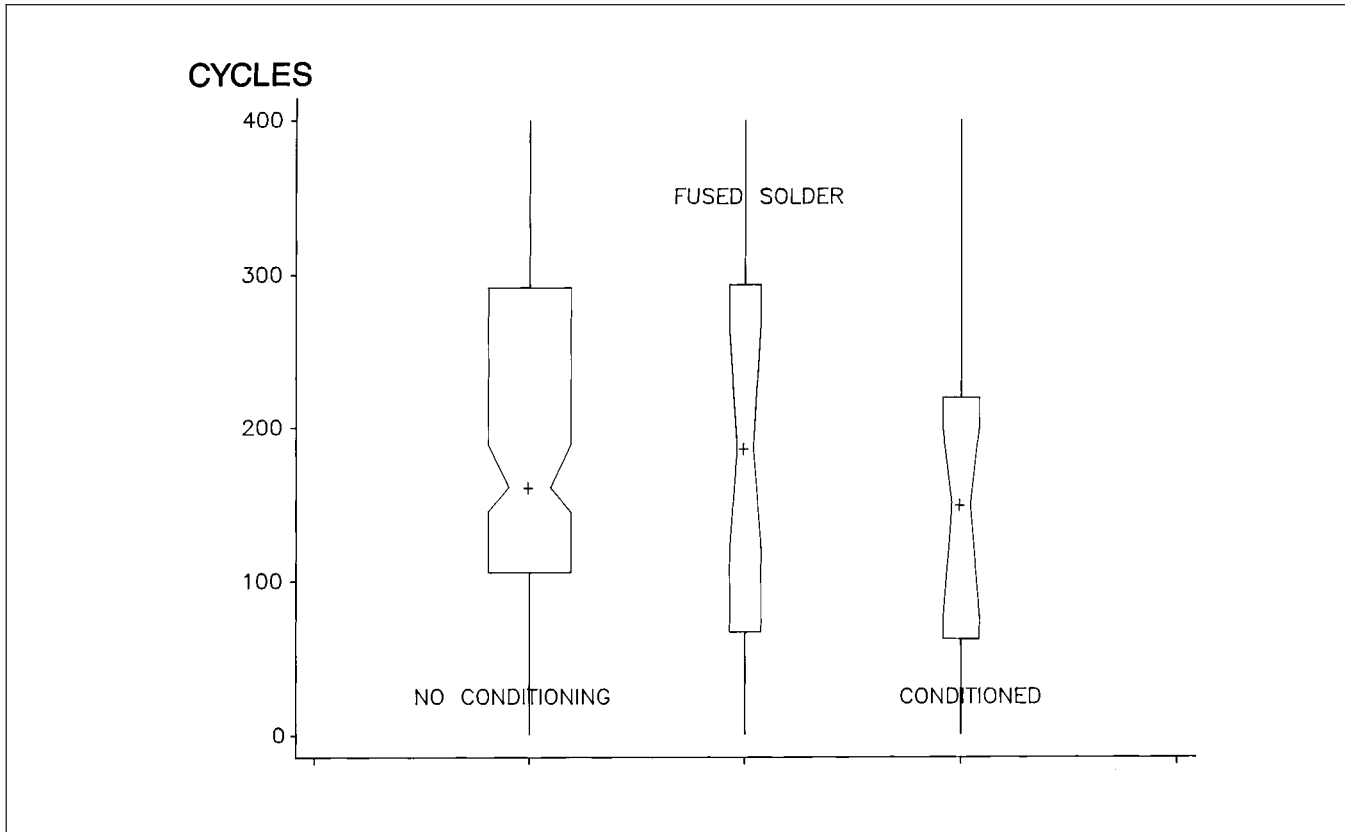


Chart 7 Cycles to failure for .090 thick PWBs vs. conditioning for MIL-T-CYCLE (all PTH diameters & board constructions)

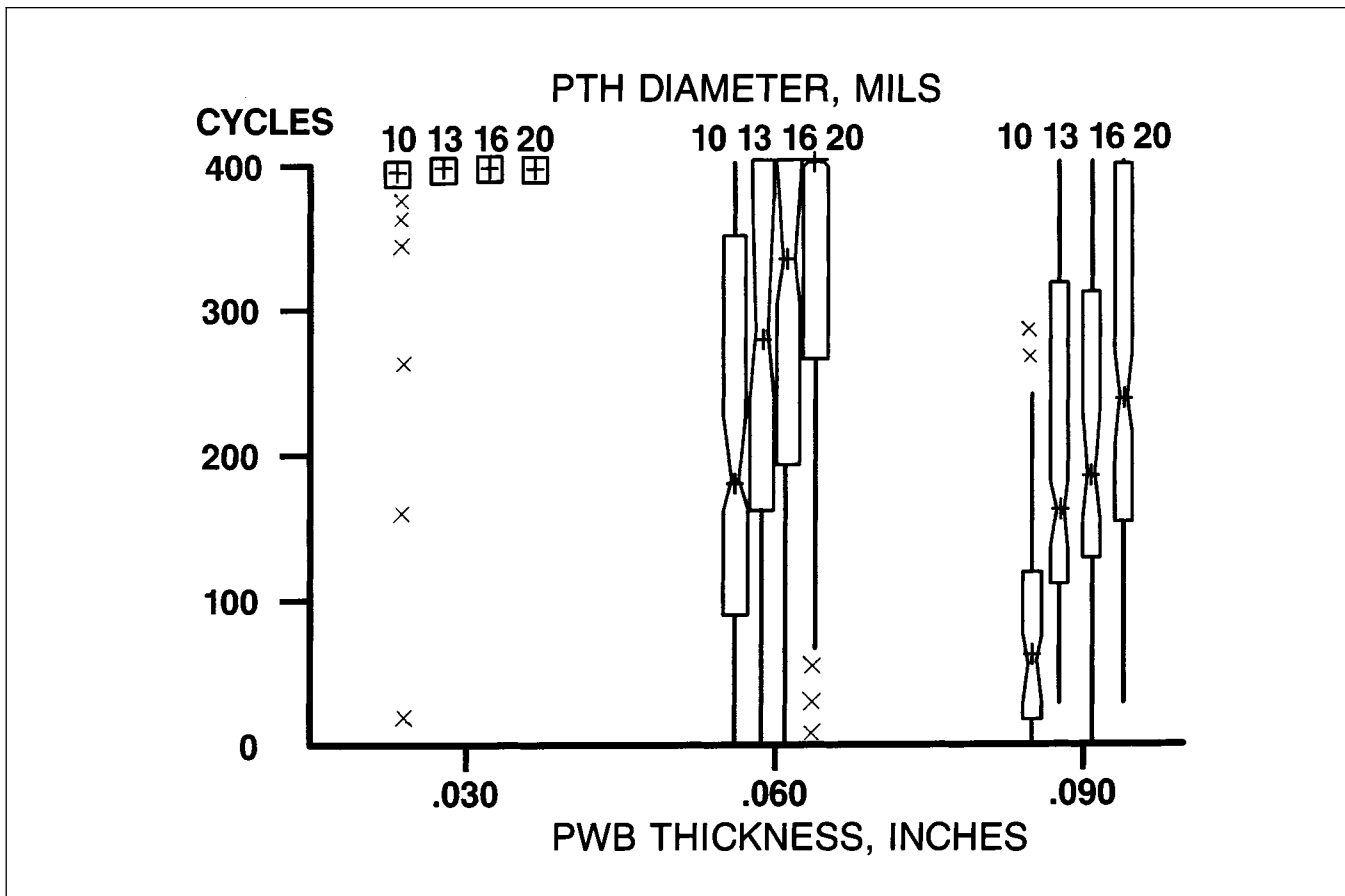


Chart 8 Cycles to failure vs. PWB thickness by PTH diameter for MIL-T-CYCLE (all board constructions)



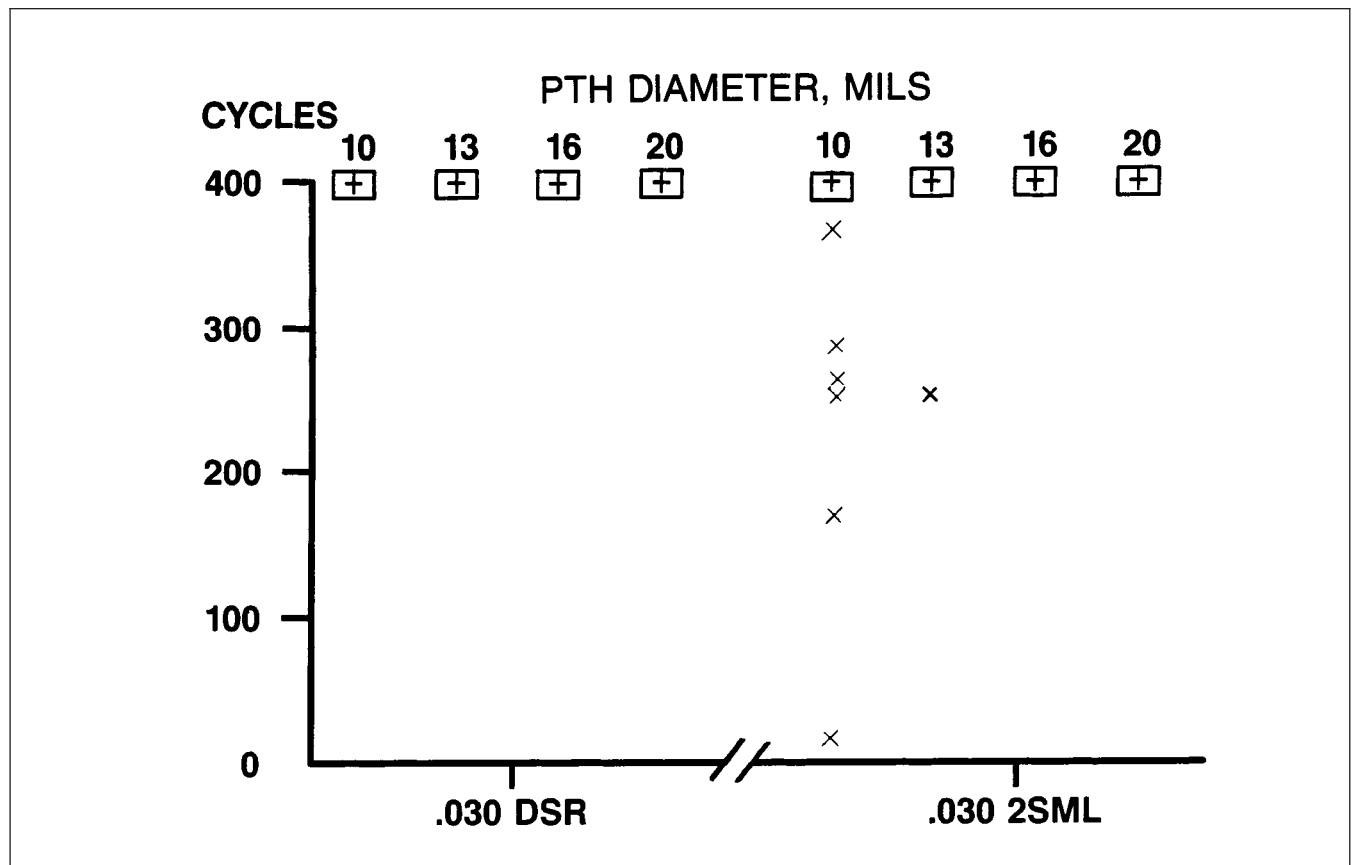


Chart 9 Cycles to failure vs. .030 thick PWBs by drill diameter for MIL-T-CYCLE

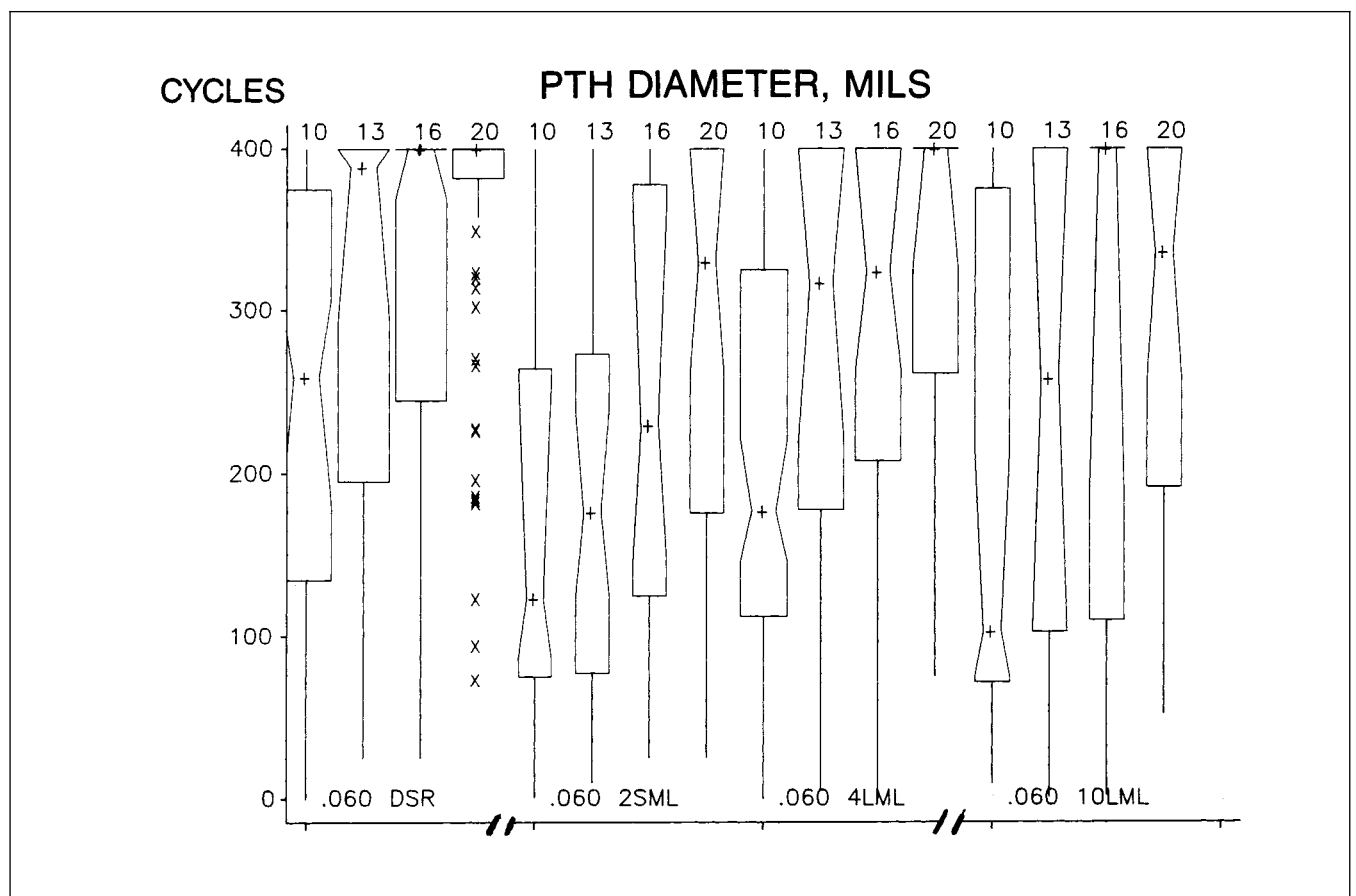


Chart 10 Cycles to failure vs. .060 thick PWBs by PTH diameter for MIL-T-CYCLE

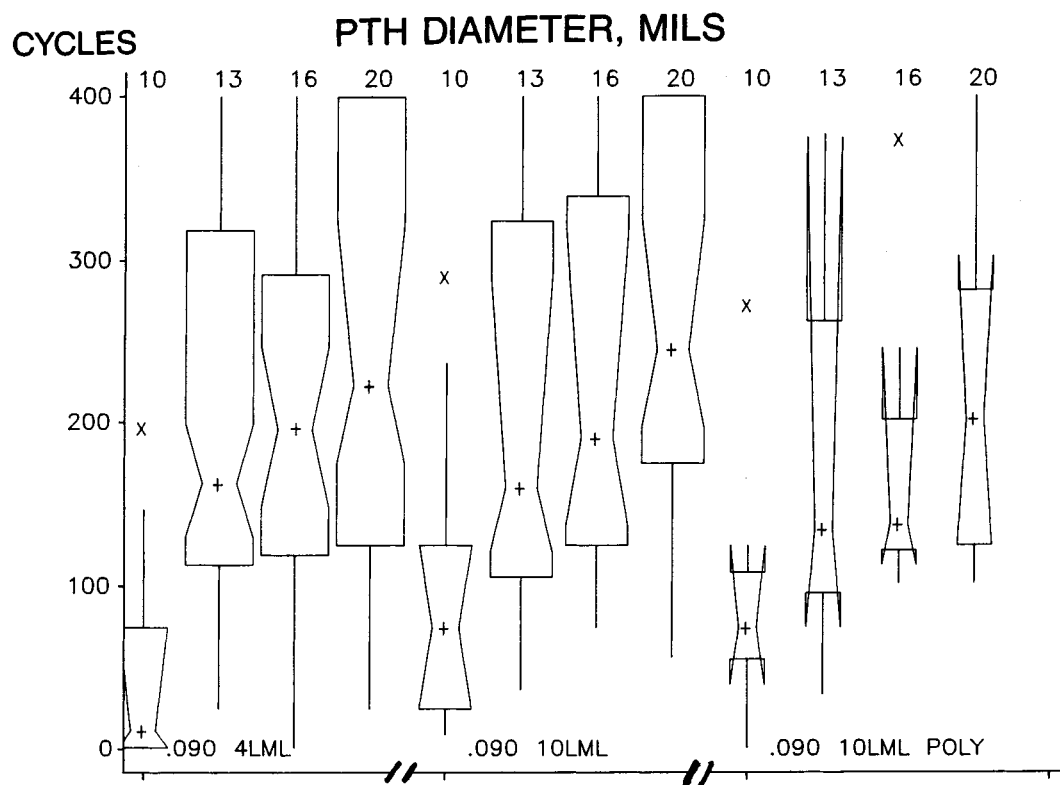


Chart 11 Cycles to failure vs. .090 thick PWBs by drill diameter for MIL-T-CYCLE

Objective

The APD OIL-T-SHOCK test was added to the round robin program to determine if this faster test correlates with the MIL-T-CYCLE test. The objective was to evaluate the ability of small diameter PTHs to survive 400 cycles of thermal shock from -35°C to + 125°C.

Test Procedure

Since the round robin was well under way when the task force chose to evaluate the APD OIL-T-SHOCK test, it was decided to test only a small sample of the test boards submitted. A representative sample (12 test boards) was selected, including both good and poor vendors as determined by the results of the MIL-T-CYCLE test. The sample covered the range of PWB constructions and thicknesses.

A liquid-to-liquid cycling environment was used to insure temperature uniformity and rapid equilibration of the test boards. Utilizing a duplicated series network for each of the four PTH diameters, variations or interruptions in electrical continuity were measured. A temperature of -35°C was chosen arbitrarily as the low temperature, but as will be seen in Section 6, this choice proved fortuitous because the test correlated well with MIL-T-CYCLE.

The test boards were exposed to a total of 400 cycles of -35°C to +125°C in a Blue M liquid-liquid shock bath. This took approximately 10 working days. Dwell time at each temperature was 15 minutes and the transfer time between the two extremes was from 10-40 seconds. A 5 centistoke Dow-Corning 200 fluid (silicone oil) was the medium in both baths. An air driven stirrer insured bath uniformity and fast equilibration times. Actual equilibration times when measured on duplicate test boards with the total bath loading the same, were less than two minutes after complete immersion (see Figure 6).

Measurements of each net's resistance were performed by removing the coupons en masse, allowing them to attain room temperature and then measuring the individual circuit resistance with an HP 4328A Milliohm meter. Short Teflon-

insulated copper multistrand wire was soldered to each net and the common ground in order to facilitate the resistance measurements. It was not possible, because of datalogger problems, to measure resistance in situ. Measurements were continued throughout the duration of the test even after boards failed. Failure was defined as a complete open. Measurements were taken after the completion of each of the following cycles: 1, 5, 10, 50, 100, 150, 200, 250, 300, 350, 400. Total measurement error on any single determination of resistance was ± 5 milliohms.

Test Results

Of the 12 test boards evaluated, six had failures in PTHs of all diameters before completion of the 400 cycles, while two had failures only in some PTHs. Four of the 12 test boards had all diameter PTHs pass the test. Figure 7 is a modified boxplot (see page 6) of the data from the APD OIL-T-SHOCK test. The vendors have been ordered from left to right to follow the same vendor order as the MIL-T-CYCLE boxplot. As only a sample of boards was taken, Figure 7 only shows data for those vendors tested.

Plotting the cycles-to-failure versus PTH diameter of all vendors (see Figure 8) shows increasing PTH reliability with increasing PTH diameter in agreement with the results for the MIL-T-CYCLE test. If the resistance change is plotted versus cycles completed (See Figures 9 and 10), the smaller diameter PTHs show abrupt, large percentage changes in resistance, while larger diameter PTHs show a more gradual increase in resistance before failure.

Conclusions

The following conclusions were drawn from the APD OIL-T-SHOCK test:

- As PTH diameters get smaller, the cyclic life decreases.
- As the PWB gets thicker, the cyclic life decreases.
- Some vendors show excellent results regardless of PTH diameter.
- In looking at net resistance, small diameter PTHs, besides failing earlier,

show an abrupt transition to open circuits: they fail catastrophically. Larger PTHs show a more gradual increase in resistance.

- Monitoring changes in actual PTH net resistance shows that the smaller the PTH diameter, and the thicker the PWB, the more abrupt (catastrophic) the failure occurs.
- Although the -35°C low temperature was chosen arbitrarily, the results correlate with MIL-T-CYCLE test results.

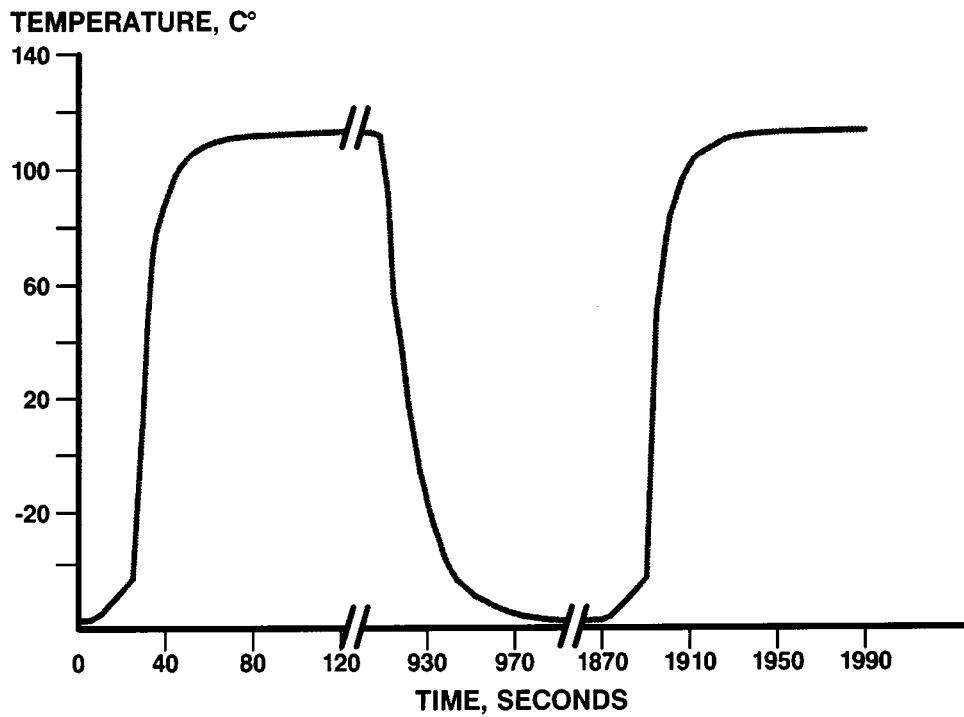


Figure 6 Actual board temperature – APD OIL-T-SHOCK

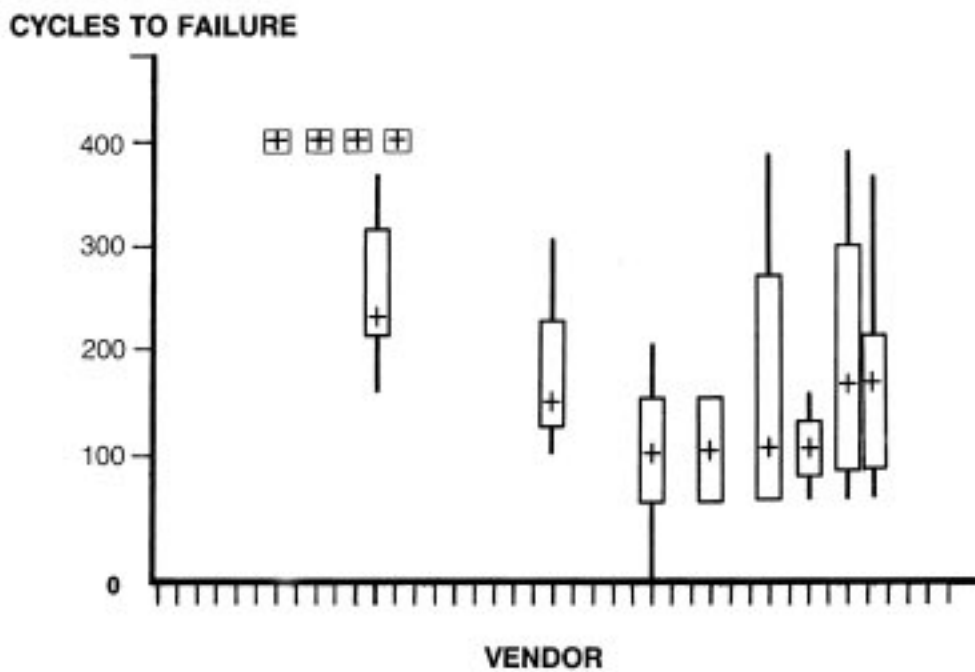


Figure 7 Cycles to failure vs. vendor for APD OIL-T-SHOCK (normal copper only, all PTH diameters – only vendors tested shown).

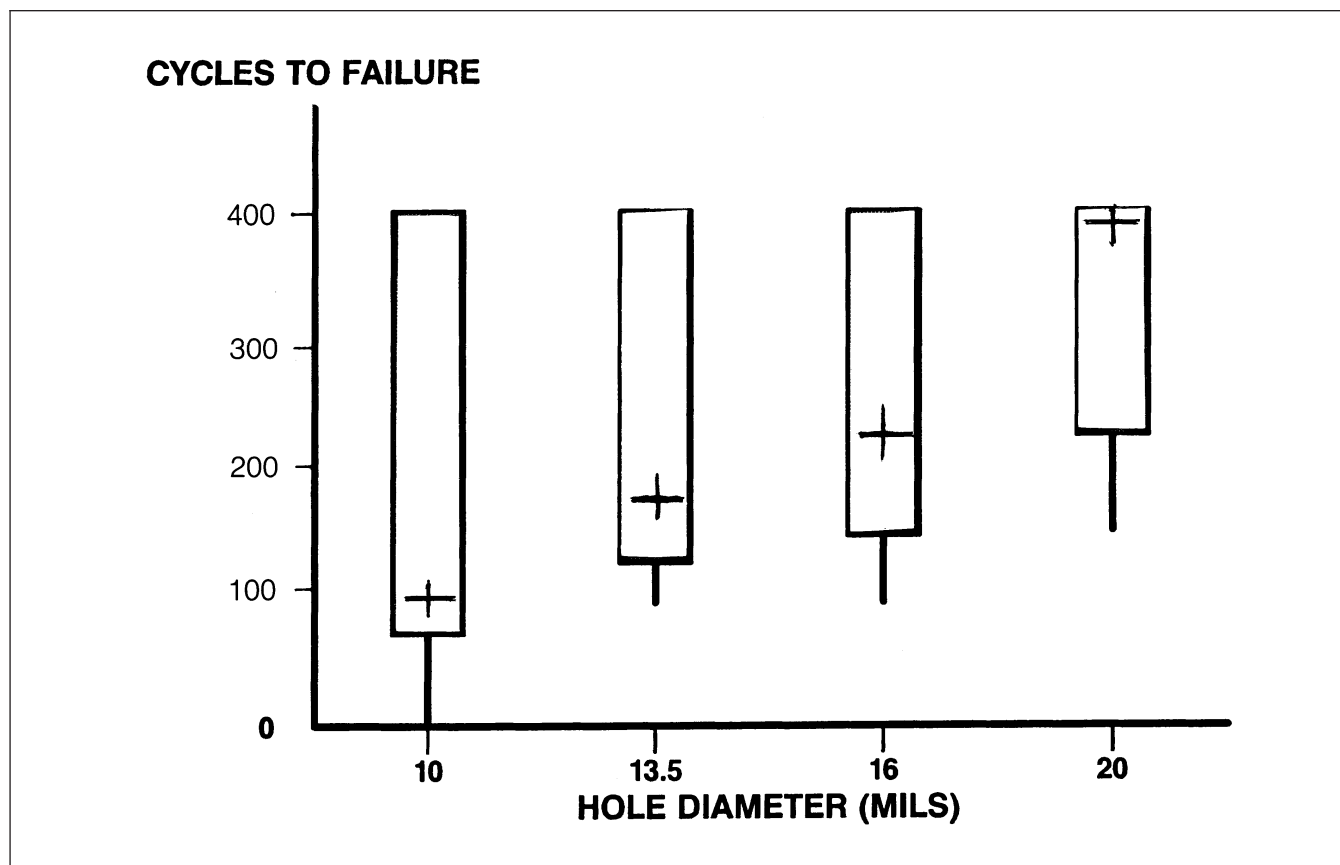


Figure 8 Cycles to failure vs. PTH diameter for ADP OIL-T-SHOCK (all PWB thickness, board constructions and vendors – normal copper only)

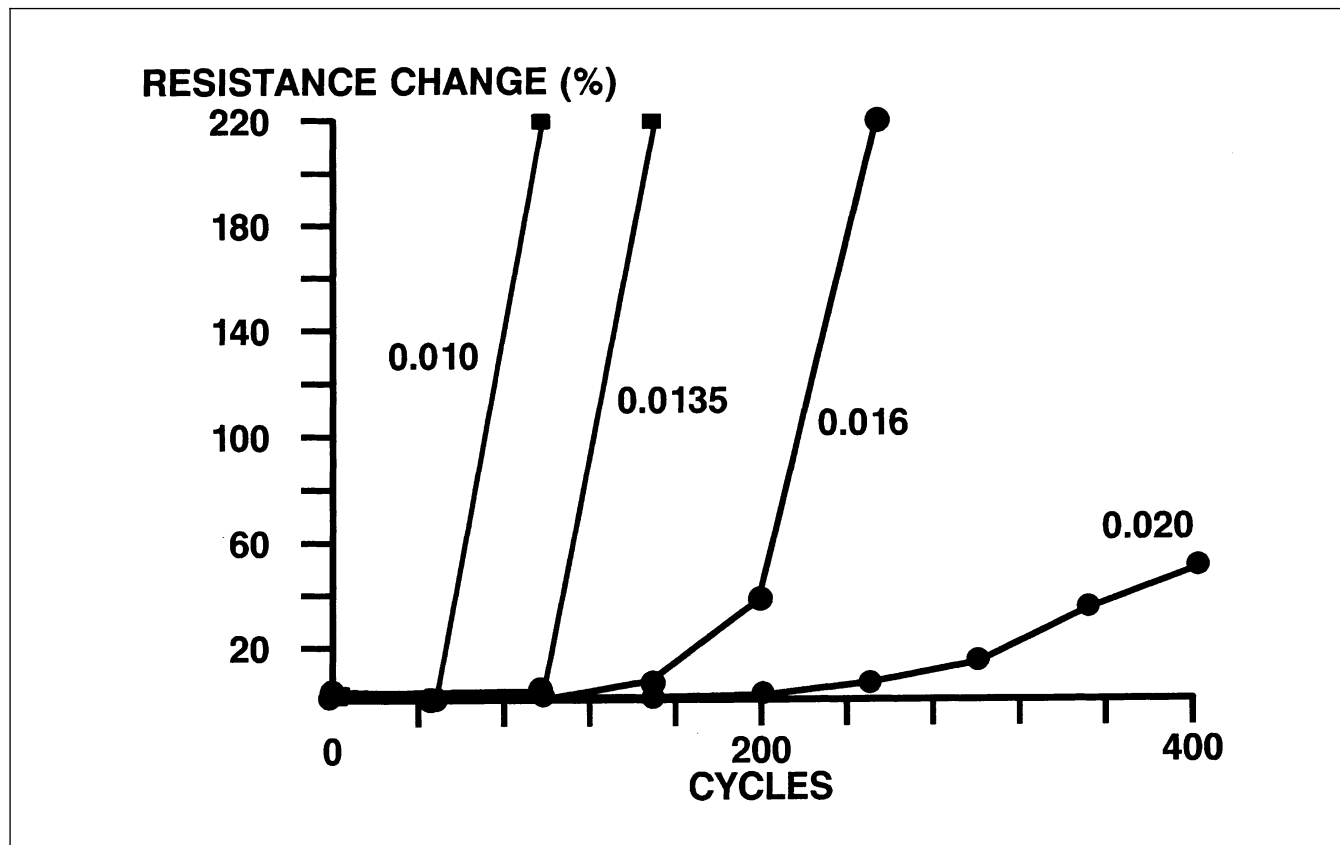


Figure 9 PTH resistance changes in 0.060 DSR during APD OIL-T-SHOCK

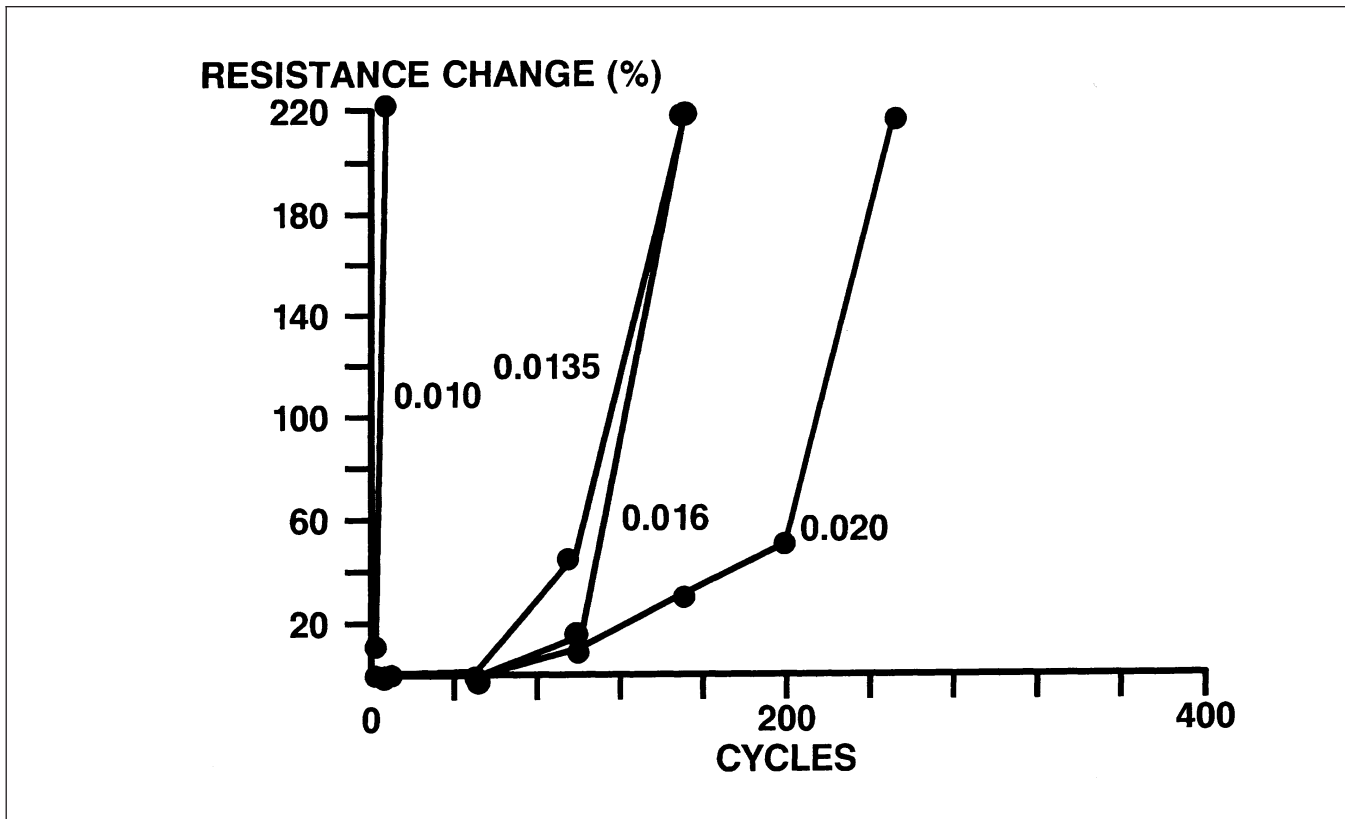


Figure 10 PTH resistance changes in 0.090 4L MLB during APD OIL-T-SHOCK

Background

The International Electrotechnical Commission (IEC) has been using an oil-to-oil thermal shock procedure for many years. The test procedure defined in IEC specification 362-2 test C is used in the international community to ascertain PTH quality. Although the +260°C high temperature is designed to simulate solder reflow, the task force decided to investigate the IEC test to determine if it correlates with the cycling tests. Therefore, the IEC OIL-T-SHOCK test was added to the program while it was ongoing.

Objective

The objective of the IEC OIL-T-SHOCK was to determine reliability and integrity of the PTHs on PWBs by monitoring continuously the electrical continuity on printed wiring boards during 10, then an additional 20 (30 total) oil dip cycles from +25°C to +260°C; and to determine whether PTH diameter, hole plating thickness, or PWB thickness affect PTH integrity and reliability. The test data were compared to the MIL-T-CYCLE results for possible correlation.

Test Procedure

The test procedure used for this evaluation is as defined in the International Electrotechnical Commission specification 362-2 test C, outlined as follows:

Labelled PWBs were received from IPC and were assembled for electrical continuity monitoring by attaching a measuring connector to a Philips dual pen recorder PM 8262. The thermal cycling was carried out by using two separate fluid baths alternately:

- An ambient temperature bath containing a low viscosity fluid (water) for efficient cooling, maintained at $+25 \pm 2^\circ\text{C}$.
- A hot oil bath (Grant bath filled with Dow Corning silicone fluid 702) maintained at $+260 \pm 5/0^\circ\text{C}$.

The test boards were immersed vertically in the fluid to a depth which left the area of connection (an edge card connector) approximately 30 mm above the surface of the fluid. The sample was

held in the +25°C bath until a stable resistance reading was obtained. After withdrawal from the +25°C bath, the fluid remaining on the test panel was removed before immersion in the +260°C bath. To improve the heat transfer during the immersion in the hot fluid, the specimen was slightly agitated.

The sample was held in the +260°C bath for 20 ± 1 seconds. The sample was then immediately transferred from the hot bath to the ambient bath and kept there until resistance stabilized again. Cycling began and ended with an immersion in the ambient bath. For this test program, each test board was subjected to 10 cycles (Standard IEC requirements) with all hole sizes being monitored. Following this exposure, all test boards were exposed to 20 additional cycles (30 cycles total) with only the .0135" holes monitored.

The resistance of the series-connected network of holes was measured at a constant measuring current of 100 ± 5 mA using the four-terminal method. Resistance was monitored continuously during the test via the Philips pen recorder. Either of two conditions constituted a failure and were recorded separately:

- (1) When measured resistance increased 100% over the resistance measured during the first 260°C immersion.
- (2) When an open circuit was encountered.

Test Results

After 10 cycles of IEC OIL-T-SHOCK, the failures were confined primarily to marginal vendors. In addition, most failures occurred in thin copper PWBs (see Figure 11 and 12). The PWB which failed at 10 cycles had all hole diameters fail almost simultaneously.

Because very few boards failed during the 10 cycle test, the task force requested that the test boards be exposed for 20 additional cycles (30 total) with only the .0135" PTHs monitored. Few additional failures occurred in the additional 20 cycles (see Figure 13). After 30 cycles, the results were again evaluated. Of 76 nets tested to 30

cycles, 60 passed completely, 14 failed with complete opens, and two failed the resistance change criterion but did not go to complete open. The failures observed in the thin copper boards were independent of board thickness.

For those vendors showing failures in this test, normal copper thickness increased cyclic life significantly.

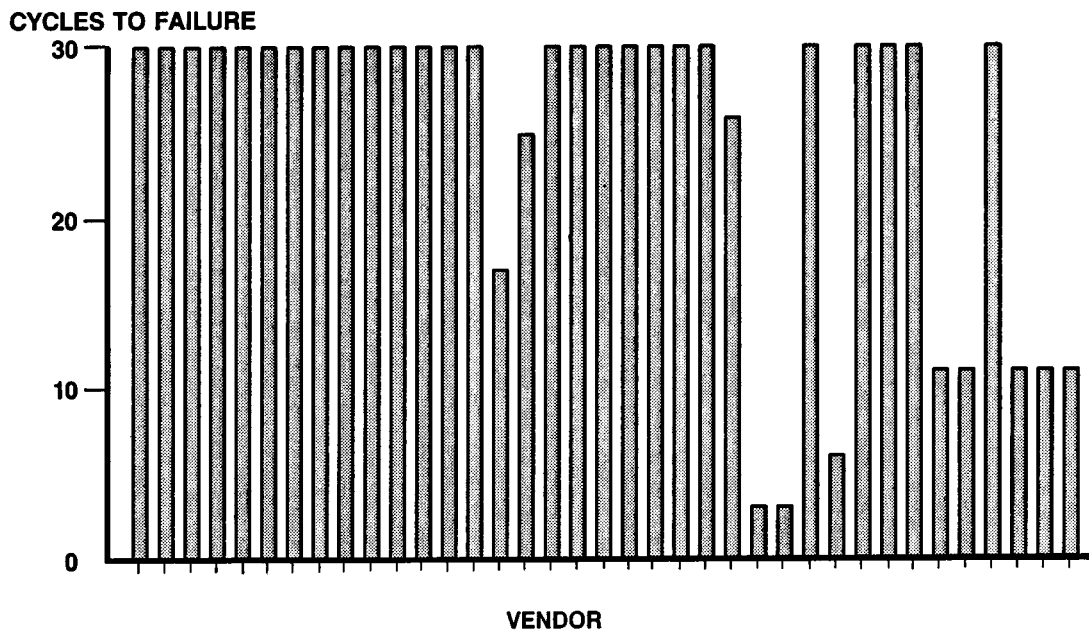
In analysis of microsections of failures, many of the PTHs failed due to barrel cracking near the center of the hole. This location was similar to that observed in the MIL-T-CYCLE test (Compare Figures 14 with 15 and 16 with 17).

Conclusions

The IEC OIL-T-SHOCK test has a greater temperature transition in a shorter time than the other test methods used except for FLUID SAND-T-SHOCK.

This test essentially resembles a repetitive solder shock test which imposes larger stresses than does thermal cycling. Thus failures, when they occur, do so in the first 10 cycles and additional cycling yields little information.

The cyclic life was independent of PTH diameter, PWB thickness and board constructions, but did depend on plating thickness. The 30 cycle test was passed by all of the vendors that were rated superior. However, the test did not consistently differentiate good and marginal vendors. The test results showed that the IEC OIL-T-SHOCK test does not correlate well with the MIL-T-CYCLE test results and has insufficient discriminating capability.



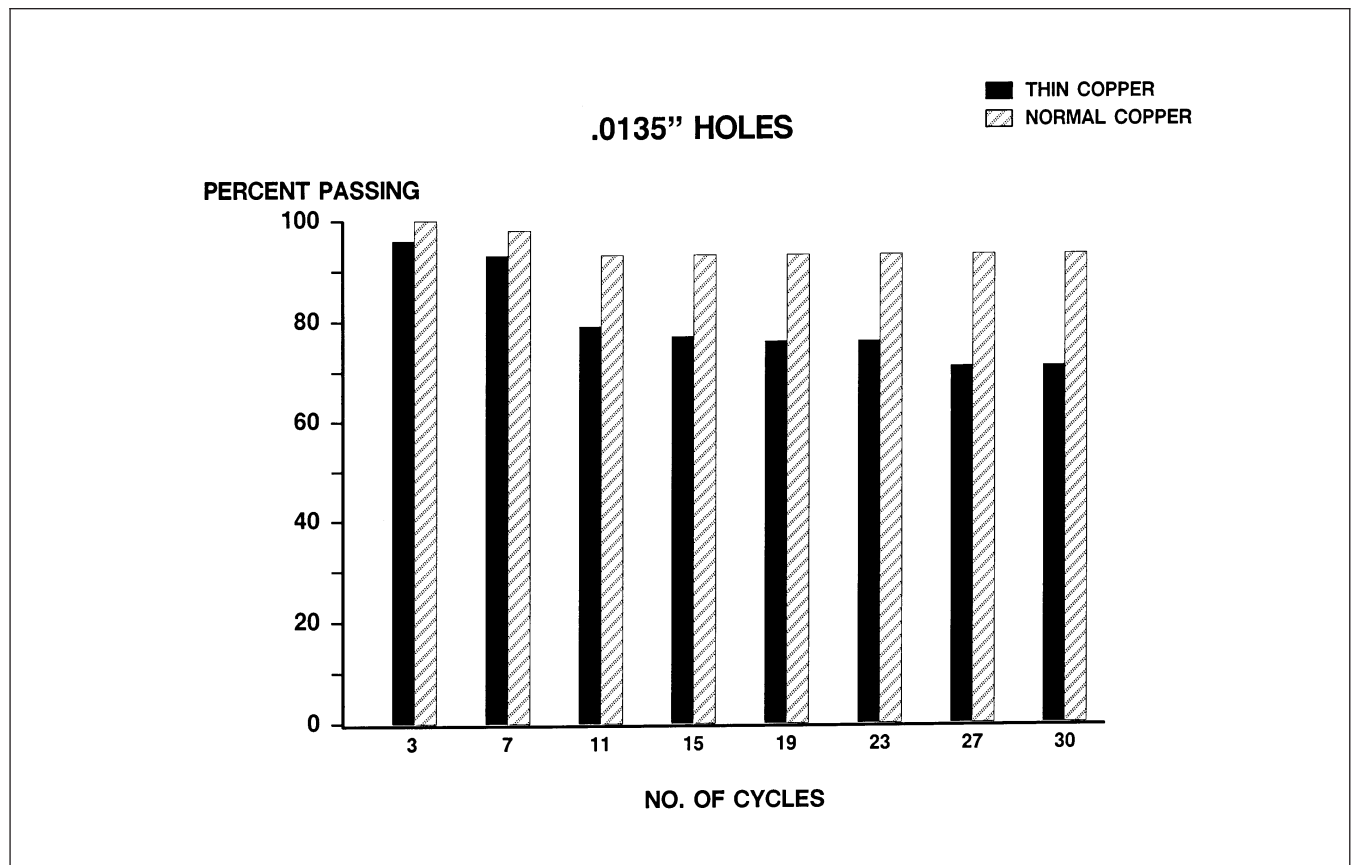


Figure 13 PTH survival vs. number of cycles of IEC OIL-T-SHOCK (.0135" PTH only, but all PWB thickness & board constructions)