

**TECHNICAL
REPORT**
**RESULTS OF COPPER FOIL
RUPTURE STRENGTH TEST
ROUND ROBIN STUDY**

The reported results are based on the work done by the Copper Foil Rupture Round Robin Task Group, chaired by Louis Zakraysek, EMK Testing Company Inc., under the auspices of the Metallic Foil Subcommittee of the Base Materials Committee of the Institute for Interconnecting and Packaging Electronic Circuits (IPC).


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Introduction

Purpose

The Metallic Foil Subcommittee of the Base Materials Committee decided in January 1987 to initiate a round robin using rupture testing to evaluate mechanical properties of foil.

The purpose was to determine if elevated temperature rupture strength testing (IPC-TM-650 Test Method 2.4.18.2) could serve as a suitable alternative to elevated temperature elongation testing (IPC-TM-650 Test Method 2.4.18) in the mechanical testing requirements of IPC-MF-150, "Metal foil for Printed Wiring Applications." Based on that purpose, the objectives were set by the subcommittee to be:

1. Evaluation of the proposed rupture test method, test method 2.4.18.2 of IPC-TM-650, "Test Methods Manual" to:
 - a. Determine critical and sensitive test method steps.
 - b. If necessary, generate the information to elucidate critical test method steps.
 - c. Determine if the test method could be performed with acceptable agreement between different test labs.
2. Evaluation of rupture testing as a means for determining the mechanical properties of electro-deposited and rolled copper foil as a function of temperature. Test results will be used to:
 - a. Establish a data base that will indicate the current range of mechanical quality (stress-rupture properties) in copper foil product from existing suppliers.
 - b. Characterize the differences between the grades of foil defined in IPC-MF-150 (especially Grades 1 and 3), and if possible, establish standard minimum values for rupture pressure and bulge height through the temperature range from room temperature to the solder float temperature of 550°F (288°C). These numbers could be used in place of elongation values in IPC-MF-150F specification sheets for mechanical properties.

Background

The usefulness of elevated temperature elongation testing for determining mechanical properties of foil came under question by the Metallic Foil Subcommittee due to problems of test result reproducibility.

Reproducibility is a problem because elongation results are very test parameter sensitive, and vastly different results are obtained for the same foil if tests are carried out using different strain rates or gauge lengths.

Summary

Most of the objectives of the round robin were fulfilled, but the consensus was not to alter the requirements for mechanical testing in IPC-MF-150.

The task group agreed that the rupture test method and procedures were valid, and the results showed that the procedure is reproducible among test labs.

A data base (data representative of production foil) of results from rupture strength testing was compiled. The data showed an overlap of rupture strength properties between the grades. Analysis of the data also showed that high temperature rupture testing results could be used to distinguish between the grades.

Due to the problem of overlap between the grades, and the contention that customers are comfortable with current elongation test results, the foil supplier community did not agree to make any changes in IPC-MF-150 mechanical testing requirements.

Therefore, rather than include rupture strength testing in IPC-MF-150 specification sheets, data compiled on a statistical number of commercial foil lots were condensed into engineering data tables (see Appendix B) for inclusion in the Application Guidelines Appendix of IPC-MF-150 (proposed).

Scope and Limitations

Test Program

The round robin was conducted in accordance with a program submitted to the IPC Metallic Foil Subcommittee (see Appendix A). The round robin was open to all suppliers and users of 1 oz copper foil.

Test Samples

Foil samples were supplied by manufacturers or users according to the existing requirements in IPC-CF-150E, and the stipulations of the Round Robin Test Program (see Appendix A). Although the test program indicates that all IPC-CF-150E types and grades would be tested, for this round robin the foils tested were restricted to samples of 1 oz Type E, Grade 1 (STD); Type E, Grade 3 (HTE); and Type W, Grade 7 (ANN). (Class designations change to grade designations in IPC-MF-150F.) Suppliers did not indicate the presence of adhesion treatments, or assign a foil profile or performance classification. Therefore, the following designations for the tested grades are listed as non-treated (a letter "N" in the designation), standard profile (a letter "S"), Class 1 types.

Tested Grades, IPC-CF-150E Designations	Tested Grades, IPC-MF-150F Designations
CF-E1-1N	IPC-MF-150/1 CU E 1-1 N S 1
CF-E3-1N	IPC-MF-150/3 CU E 3-1 N S 1
CF-W7-1N	IPC-MF-150/7 CU W 7-1 N S 1

Test Methods

Representative sample panels were tested by test laboratories according to the requirements of the test method for foil hot rupture strength, Method 2.4.18.2 of IPC-TM-650 (see Appendix C), and the Round Robin Test Program (see Appendix A).

The option was available of conducting tensile strength and elongation tests on the same lots that went through rupture testing. The purpose of this option was to be able to make correlative comparisons in the trends in mechanical strength values as determined by either of the test methods. Tensile strength and elongation tests were conducted according to the test method for foil tensile strength and elongation, Method 2.4.18 of IPC-TM-650 (see Appendix C).

Only two test labs choose to conduct tensile strength and elongation tests. These tests were conducted only during round 2 (see under "Procedure" for an explanation of the Rounds). No tensile strength tests were conducted at 550 °F (288 °C), since there is no standard requirement to do tests at temperatures higher than 350 °F (177 °C). Therefore, comparisons are somewhat limited in this respect.

Procedure

The test program was divided into two rounds. Round 1 was run for the purpose of validating the rupture test method, and verifying consistency of results among test labs. Round 2 was then conducted to compile rupture data on a statistical number of commercial foil lots.

Participants

In Round 1, samples representing 1 lot each of the three foil grades were submitted to the IPC by three foil suppliers. The IPC then distributed test pieces to 9 test labs. See Appendix D for a list of participants.

In Round 2, the intention was that 15 lots of each grade would be tested. The majority of samples were selected and tested by foil suppliers. For independent verification, smaller sample quantities were submitted to the IPC and re-distributed to independent test labs. Another group of samples was submitted to the IPC by foil suppliers and users, and these samples were also distributed to the independent labs. See Appendix D for a list of participants.

Reproducibility of Rupture Strength Test Method—Round 1

Nine laboratories participated (see Appendix D) in Round 1 of the round robin to determine consistency among test facilities.

For this series of tests, each laboratory tested nine weighed samples representing each of the foil grades. Each laboratory made tests at 75 °F (24 °C, room temperature or "RT"), 350 °F (177 °C), and 550 °F (288 °C). The test results have been processed on a spread sheet to record the average values; as well as the standard deviation for the set of tested samples.

In this evaluation of the test results, none of the data were filtered for obviously defective samples, or for any other reason.

Tables 1-1 through 1-6 present a compilation of the condensed test results for all of the tests. Average and standard deviation values for rupture pressure or bulge height are presented at the top of each table. At the bottom of each table is a summary that shows the maximum, average, minimum, and standard deviation for the average values given above.

Test results for Type E, grade 1 (std) foil

Type E, Grade 1 (STD) foil is referred to as standard (STD) electrodeposited foil in IPC-MF-150. This grade of electrolytic foil has no IPC mechanical test requirements at elevated temperatures.

The test results presented in Tables 1-1 and 1-2 indicate that the hot rupture properties of this grade of foil degrade rapidly.

Test lab results, however, were the most consistent at the higher temperatures. Overall, these data show good agreement in results among test laboratories.

Test results for Type E, grade 3 (HTE) foil

Type E, Grade 3 foil is referred to as high temperature elongation (HTE) electrodeposited foil in IPC-MF-150. This grade of foil has IPC mechanical test requirements at room temperature and 350 °F (177 °C).

The test results presented in Tables 1-3 and 1-4 indicate that the hot rupture properties of Grade 3 foil can be considerably higher than those of Grade 1. The difference in hot rupture properties permits the characterization of these grades.

Again, there is reasonably good agreement in test results among test laboratories. Agreement among laboratories is best at 550 °F (288 °C) for the rupture pressure results, but best at 350 °F (177 °C) for bulge height results.

Test results for type W, grade 7 (ANN) foil

Type W, Grade 7 foil is referred to as annealed-wrought (ANN) foil in IPC-MF-150. This grade is wrought foil, with characteristics that are entirely different from those of electrolytic foil. Grade 7 consistently exhibits high elongation at all test temperatures.

The test results presented in Tables 1-5 and 1-6 indicate that the hot rupture properties of this grade of foil are not susceptible to abnormal degradation with temperature; though rupture strength does decrease somewhat at the higher temperatures. These data show high bulge heights and high rupture values, even in comparison to the Grade 3 foils.

The results for Grade 7 foils showed very good agreement among test laboratories.

Conclusions—Round 1

The results of tests during the first round of the Foil Rupture Round Robin showed that rupture testing to Method 2.4.18.2 of IPC-TM-650 provided reproducible test results among participating laboratories. Agreement was best with Type W, Grade 7 annealed wrought foil, followed by Type E, Grade 1 standard foil, and Type E, Grade 3 high temperature elongation foil.

In addition, the three grades were distinguishable by results of tests conducted at 550 °F (288 °C). Variations in hot mechanical quality between the electrolytic grades (Grades 1 and 3) are readily discernible.

Table 1-1 Average Rupture Pressure for 1 oz. Type E, Grade 1 Foil

Test Lab	75 °F		350 °F		550 °F	
	RP (psig)	Std Dev	RP (psig)	Std Dev	RP (psig)	Std Dev
E	42.8	3.7	23.6	1.3	15.1	0.7
I	38.2	2.1	25.1	3.0	16.0	2.0
J	37.4	5.8	15.9	1.2	9.6	0.5
K	-	-	21.7	3.4	11.3	0.8
A	44.1	1.5	24.8	1.7	14.4	2.6
B	48.9	4.6	22.7	1.7	13.9	0.7
O	43.1	2.1	22.2	3.2	14.9	2.7
G	40.1	6.8	20.8	3.5	12.7	1.5
D	45.0	4.7	36.5	2.5	15.1	0.7
Max	48.9		36.5		16.0	
Avg	42.5		23.7		13.7	
Min	37.4		15.9		9.6	
Std Dev		3.5		5.2		2.0

Table 1-2 Average Bulge Height for 1 oz Type E, Grade 1 Foil

Test Lab	75 °F		350 °F		550 °F	
	Ht (mils)	Std Dev	Ht (mils)	Std Dev	Ht (mils)	Std Dev
E	181	10	127	6	104	3
I	179	21	149	12	125	8
J	74	21	46	10	70	5
K	-	-	103	12	62	5
A	194	7	151	10	127	15
B	223	18	126	13	113	5
O	168	8	109	28	91	12
G	182	28	118	14	98	9
D	186	17	176	9	131	9
Max	223		176		131	
Avg	173		123		102	
Min	74		46		62	
Std Dev		40		35		23
RP - Rupture Pressure						
Ht - Height						
Std Dev - Standard Deviation						

Table 1-3 Average Rupture Pressure for 1 oz. Type E, Grade 3 Foil

Test Lab	75 °F		350 °F		550 °F	
	RP (psig)	Std Dev	RP (psig)	Std Dev	RP (psig)	Std Dev
E	77.2	5.3	41.1	4.6	21.9	2.0
I	85.5	7.5	43.3	3.4	24.7	3.4
J	87.3	7.7	31.8	1.3	18.0	2.7
K	72.5	7.5	39.3	6.1	22.1	1.5
A	69.0	11.2	41.0	3.7	27.1	2.3
B	89.9	5.9	36.4	3.0	33.0	5.7
O	77.8	6.7	46.4	3.4	21.9	2.0
G	74.0	6.3	32.5	1.5	26.9	4.1
D	80.8	18.6	53.0	2.4	30.0	3.8
Max	89.9		53.0		33.0	
Avg	79.3		40.5		25.1	
Min	69.0		31.8		18.0	
Std Dev		6.7		6.3		4.4

Table 1-4 Average Bulge Height for 1 oz Type E, Grade 1 Foil

Test Lab	75 °F		350 °F		550 °F	
	Ht (mils)	Std Dev	Ht (mils)	Std Dev	Ht (mils)	Std Dev
E	276	25	164	18	128	7
I	290	30	193	5	173	30
J	181	25	82	12	100	22
K	224	25	131	21	105	10
A	230	37	182	22	194	21
B	312	23	150	14	260	49
O	242	27	170	12	121	11
G	297	55	139	6	215	49
D	259	58	192	9	178	22
Max	312		193		260	
Avg	257		156		164	
Min	181		82		100	
Std Dev		39		33		51

RP - Rupture Pressure
 Ht - Height
 Std Dev - Standard Deviation

Table 1-5 Average Rupture Pressure for 1 oz. Type W, Grade 7 Foil

Test Lab	75 °F		350 °F		550 °F	
	RP (psig)	Std Dev	RP (psig)	Std Dev	RP (psig)	Std Dev
E	58.3	1.3	47.0	2.3	38.9	0.7
I	61.1	0.6	44.7	1.3	39.2	1.2
J	59.4	1.8	45.1	3.4	35.6	1.0
K	56.4	0.9	43.8	0.9	35.8	1.2
A	58.4	1.9	49.3	1.2	38.6	1.1
B	57.7	2.0	44.9	0.8	35.1	0.6
O	60.1	1.4	50.3	1.8	44.6	1.2
G	54.2	1.9	44.3	1.5	36.5	0.8
D	66.9	1.3	55.6	0.7	46.2	1.0
Max	66.9		55.6		46.2	
Avg	59.2		47.2		38.9	
Min	54.2		43.8		35.1	
Std Dev		3.3		3.7		3.8

Table 1-6 Average Bulge Height for 1 oz Type W, Grade 7 Foil

Test Lab	75 °F		350 °F		550 °F	
	Ht (mils)	Std Dev	Ht (mils)	Std Dev	Ht (mils)	Std Dev
E	432	7	405	5	382	5
I	443	5	411	6	402	6
J	329	24	334	18	338	13
K	406	4	372	7	345	12
A	410	48	451	13	404	15
B	435	12	410	12	384	7
O	416	11	403	7	379	3
G	418	14	407	9	383	8
D	452	8	428	4	402	7
Max	452		451		404	
Avg	416		402		380	
Min	329		334		338	
Std Dev		34		31		23

RP - Rupture Pressure
 Ht - Height
 Std Dev - Standard Deviation

Rupture Strength Properties of Commercial Copper Foil—Round 2

Suppliers, laminators, users, and independent test laboratories participated in Round 2 of the round robin (see Appendix D for list of participants). This was done to establish rupture test values that are representative of present day production quality foil. No attempt was made to upgrade foil quality levels during the round robin.

Limitations

The intention was that 15 lots of each grade would be tested by each laboratory. However, reported results have been confined to a smaller set of samples in most instances. For Type E, Grade 1, results for a minimum of 15 lots have been reported only in the case of Laboratory D. For Type E, Grade 3, results for 15 lots have been reported only in the case of Laboratory B. For Type W, Grade 7, only 1 lot was tested (results are reported from two independent laboratories).

In addition, reported results are limited as to the number of sources of samples. For Type E, Grade 1, results have been reported for only 3 sources (Sources A, B, and D). For Type E, Grade 3, results have been reported for only 2 sources (Sources B and D). For Type W, Grade 7, results have been reported for only 1 source (Source C).

Note: Sources and labs are not shown in the tables of condensed information tables for Types E, Grades 1 and 3. Sources and labs are shown for Type W, Grade 7.

Rupture pressure results

Rupture pressure values are recorded in Tables 2-1, 2-2, and 2-3.

Table 2-1 shows the condensed data for Type E, Grade 1 foil; and Table 2-2 shows the condensed data for Type E, Grade 3 foil. The three columns of information, from left to right, are maximum, average, and minimum values from all lots tested. The rows of information are maximums of those values (first row), averages of those values (second row), or minimums of those values (third row). The diagonal of values, from top left to bottom right, shows the absolute maximum, average, and minimum values from all reported results. These sets of readings are grouped according to the three different test temperatures.

When reading Tables 2-1 and 2-2, each row breaks down as follows: The first row shows, from left to right, the maximum of the maximum values from each lot (the absolute maximum from all lots), the maximum of the average values from each lot, and the maximum of the minimum values from each lot. The second row shows, from left to right, the average of the maximum values from each lot, the average of the average values from each lot (the absolute average), and the average of the minimum values from each lot. The third row shows, from left to right, the minimum of the maximum values of each lot, the average of the minimum values of each lot, and the minimum of the minimum values of each lot (the absolute minimum).

No standard deviation is shown for Tables 2-1 and 2-2 since the number of tested samples within a lot varied. The rupture test method requires the testing of 3 samples per lot. Some testers chose to test 9 samples per lot.

Table 2-3 shows the rupture pressure values for Type W, Grade 7 foil. These data represent only 1 lot of annealed wrought foil. The three columns of information, from left to right, are maximum, average, and minimum values of the tested lot. The two rows are readings taken by two different laboratories. The readings are grouped according to the three different test temperatures.

Bulge height results

Bulge height values are recorded in Tables 2-4, 2-5, and 2-6.

These tables are constructed in the same manner as Tables 2-1, 2-2, and 2-3. The comments and explanations in the section on Round 2 rupture pressure results also apply to these tables.

Conclusions—round 2 rupture strength tests

Rupture Pressure Results—75°F

Rupture pressure results at 75°F (24°C) indicate that the average values are the most useful for distinguishing between the three grades. Type E, Grade 3 shows the highest results (82.1 psig, absolute average), fol-

lowed by Type E, Grade 1 (62.9 psig, absolute average), and Type W, Grade 7 (38.4 psig, highest average). Maximum values converge for Type E, Grades 1 and 3; and minimum values are close for Type E, Grade 1, and Type W, Grade 7. Values for Type E, Grades 1 and 3 overlap.

Rupture Pressure Results—350°F

Rupture pressure results at 350°F (177°C) indicate that the maximum values are the most useful for distinguishing between the three grades. Type E, Grade 3, shows the highest results (72.2 psig), followed by Type E, Grade 1 (60.0 psig), and Type W, Grade 7 (34.2 psig). Minimum and average values are close for Type E, Grade 1, and Type W, Grade 7. Both Type E, Grade 3, and Type W, Grade 7 values overlap with Type E, Grade 1 values. Type E, Grade 3, and Type W, Grade 7 values are clearly distinguishable.

Rupture Pressure Results—550°F

Rupture pressure results at 550°F (288°C) indicate that the maximum values are most useful for distinguishing between the three grades. Type E, Grade 3 shows the highest results (65.0 psig), followed by Type E, Grade 1 (43.4 psig), and Type W, Grade 7 (28.0 psig). Minimum and average values are close for Type E, Grade 1, and Type W, Grade 7. Both Type E, Grade 3, and Type W, Grade 7 values overlap with Type E, Grade 1 values. Type E, Grade 3, and Type W, Grade 7 values are clearly distinguishable.

Usefulness of Rupture Pressure Data

Using rupture pressure data, the maximum values from tests at 550°F (288°C) are the most useful for characterizing the grades because there is the clearest margin of demarcation between those values. Type E, Grade 3 exhibits the highest rupture pressure values at all temperatures, followed by Type E, Grade 1, and Type W, Grade 7. Type W, Grade 7 test results show the least variance in rupture strength across the range of test temperatures. As the test temperature is increased, the trend is towards lower rupture pressure values for all three grades.



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