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GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

EVALUATION AND COMPARATIVE ANALYSIS OF CONFORMAL COATING MATERIALS

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EVALUATION AND
COMPARATIVE ANALYSIS
OF
CONFORMAL COATING MATERIALS

By

Equipment Production and Evaluation Section

George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

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This report is a comparative analysis of castable polyurethane materials and thin film forming materials used as ESE environmental protective coating. The castable polyurethanes were designed and primarily intended for potting and molding of cable terminations; however, more recently they have been used as conformal coating for ESE. The thin film forming materials are designed and developed specifically as environmental protective coatings for ESE applications.

The castable polyurethane materials and the thin film forming materials were evaluated by R-ASTR-ESE at the request of KSC Quality Assurance Division, for conformance to a set of ideal ESE coating requirements designed to eliminate production and performance problems reported by NASA, KSC, and affiliated contractor personnel. Evaluation results show that thin film materials conform more closely to the ideal requirements than do castable polyurethanes. The use of thin film forming materials for conformal coating ESE will eliminate most current production problems, will provide a higher degree of performance reliability, and will substantially reduce costs.

Author

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UNUSUAL TERMS

CONFORMAL COAT - A coating of relatively uniform thickness that conforms to the configuration of an irregular object.

APPLICATION LIFE - The time from completion of blending of a mix to the time when that mix has a viscosity unsuitable for application; for example, a material was blended and it was 8 hours (application life) before that material had an unworkable viscosity.

Q-FACTOR - Energy lost from an electrical component or group of components when charged, the Q-factor is expressed as the ratio of reactance (effect of capacitance, X_C, or inductance X_L, and frequency combined) to the resistance of the electrical device.

NONSTANDARD ABBREVIATIONS

CO_2	Carbon dixoide
$N.s/m^2$	Newton seconds per square meter
C	Celsius
R-ASTR-ESE	Equipment Production and Evaluation Section, Astrionics Laboratory

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EVALUATION AND
COMPARATIVE ANALYSIS
OF
CONFORMAL COATING MATERIALS

SUMMARY

This report analyzes and compares two types of conformal coating materials for ESE--castable polyurethane and thin film forming. The castable polyurethane materials primarily were approved for cable termination potting or molding, but more recently have been used as ESE conformal coating.

Problems arising from use of the castable materials as conformal coating prompted KSC to request an investigation by R-ASTR-ESE, which validated all problem reports, established with KSC ideal conformal coating requirements, and produced 3 high performance thin film forming materials specifically designed for environmental protection of ESE.

The castable polyurethane materials and the thin film forming materials were evaluated by R-ASTR-ESE for conformance to the ideal conformal coating requirements. Evaluation results show that the thin film materials conform more closely to those requirements than do the castable materials. Therefore, the use of thin film materials for conformal coating of ESE will eliminate most current production problems, will provide a higher degree of performance reliability, and will substantially reduce costs to NASA.

Based upon the results of this analysis, it is recommended that thin film forming materials be utilized for ESE requiring an environmental protective coating.

SECTION I. INTRODUCTION

This report is a comparative analysis made by R-ASTR-ESE of castable polyurethane potting and molding materials widely used as a conformal coating, and of materials specifically designed and developed for thin film coatings of ESE. The need for an improved environmental protective coating was recognized by MSFC, KSC, other NASA centers, and NASA affiliated contractor personnel to resolve production and performance problems with castable polyurethane. R-ASTR-ESE, as a responsible design evaluation function and being particularly oriented to insulation material applications and failure fact analysis, was requested by KSC to initiate action that ultimately would result in a compatible solution of ESE coating problems.

After identification and validity of the problems were established, R-ASTR-ESE did research to determine ideal requirements for ESE conformal coating. The results are recorded in table I. The research not only yielded ideal requirements but also yielded 11 materials designed and developed for use as a thin film coating. These 11 thin film coating materials were subjected to preliminary evaluation and 3 were chosen for final evaluation and for comparison with castable polyurethanes. The complete materials evaluation is discussed in section III, and evaluation results are recorded in tables II and III.

The materials evaluation test data are compared and analyzed in section IV, and section V discusses recommendations and conclusions derived from the data analysis.

SECTION II. STUDY PROGRAM

A. REQUIREMENTS STUDY

Conformal coating of ESE printed circuit assemblies is required for the following 3 reasons:

1. To provide protection for the assemblies, from the time of manufacture throughout service life, against adverse environmental conditions.

2. To provide electrical insulation of one component and one circuit from another component or circuit.

3. To provide mechanical reinforcement (ruggedization) for components that will help them withstand, without damage, launch vibrations.

B. PROBLEM STUDY

A variety of problems encountered by users of castable polyurethane for ESE conformal coating have been reported to R-ASTR-ESE. At the request of KSC, R-ASTR-ESE made a study to validate all problem reports; to establish, with KSC, requirements for a conformal coating material that will alleviate problem areas; and to determine if materials actually were available that could meet the established product requirements.

1. Problem Validity. Problems reported to R-ASTR-ESE were numerous and frequent. Therefore, R-ASTR-ESE and KSC started investigation to determine if the problems actually were valid by sending representatives into the respective manufacturing areas to study coating techniques, materials, environmental conditions, and personnel handling the conformal coating materials. The investigation was continued at R-ASTR-ESE where personnel were able to simulate certain problems in the laboratory.

The investigation validated the following problems, most of which are associated with poor handling and processing characteristics and lack of desirable electrical properties:

a. Time consuming heat process. The castable polyurethane conformal coatings come in 2 parts (curing agent and base material), one of which is usually crystallized (normally the curing agent). The crystallized part must be heated to approximately 92 to 98 degrees C and then allowed to cool and stablize at room temperature before being blended with the base material. This heating, cooling, and stablization is very clumsy and time consuming for a manufacturer dealing with mass production items.

b. Time consuming degassing process. After the 2 parts have stabilized at room temperature, the materials are mixed thoroughly. During mixing, air is entrapped in the compound and, in the presence of moisture, may cause carbon dixoide (CO_2) to form. This entrapped CO_2 and air make vacuum degassing necessary. This degassing process wastes material, causes extra handling, and is very time consuming.

c. High initial viscosity. The 2 blended parts have a very high initial viscosity--approximately 10 to 35 $N.s/m^2$ (10,000 to 35,000 centipoises)--which is not conducive to brushing and dipping, and can be sprayed only with costly proprietary spray equipment.

d. Time consuming masking process. Before a castable polyurethane coating can be applied to an assembly, masking is necessary on the board edges and on any other areas not requiring coating. Conformal coating on edges would make them too thick to integrate with other equipment. The masking process is slow and time consuming, and thereby costly. In addition, masking leaves the cut board edges unsealed. These unsealed edges are the major avenues of moisture penetration.

e. Short application life. After completion of mixing and degassing, application life of the castable polyurethane compound is approximately 30 to 45 minutes. This short application life is tolerable for casting or potting and molding cable termination, but is too short for production coating operations. This limited application time frequently is the reason for wasted coating materials and occasionally is the reason for nonacceptable coating on fully assembled circuitry. Therefore, this circuitry is rendered useless.

f. Time consuming cure process. The coated assemblies are documented to be cured by placing them in a preheated oven at 50 to 60 degrees C for 14 hours minimum and then allowing them to gradually cool to room temperature. In reality, the time required to cure the coated assemblies is approximately 24 to 30 hours at 50 to 60 degrees C. If the coated item is to be electrical tested, it must stabilize at room temperature for an additional 24 hours prior to testing. This cure process for mass production requires the use of too many ovens for an excessive period of time--often requiring additional capital expenditures for curing equipment. Not only is there additional equipment expenditure, there also is additional expenditure for overtime or second shift personnel required to maintain these ovens throughout the long cure period.

g. Excessive coating thickness. Castable polyurethane conformal coatings on ESE are documented to be applied 0.013 to 0.0064 centimeter (0.005 to 0.025 inch) thick, with greater buildup or filleting around components, and be acceptable by quality inspection. However, investigation by R-ASTR-ESE and

KSC indicated that capacitance buildup (Q-factor) is a valid problem primarily caused by excessive coating thickness. Thermal expansion forces to circuitry components is a known problem probably contributed to thick coatings; however, this reported problem area was not validated by R-ASTR-ESE and KSC in this program.

(1) Capacitance buildup (Q-factor). Q-factor is the added capacitance that interferes with operation of electrical equipment. With non-critical or low impedance circuitry, added capacitance is no problem. But with critical or high impedance circuitry, this added capacitance can change circuitry characteristics so drastically that major retuning is necessary or they cannot be returned to their precoated operating parameters and must be redesigned.

(2) Thermal stress. Experience has shown that the operational thermal range of ESE coated with thick organic polymers can cause significant and damaging stresses on delicate components and solder joints utilized in printed circuit designs.

2. Ideal Conformal Coating Requirements. The problem study by R-ASTR-ESE and KSC not only validated problems, but also resulted in a list of ideal requirements for conformal coating materials which would alleviate all or most problems associated with conformal coated ESE. These ideal requirements--derived from coating material manufacturers, from manufacturers who apply these coatings to ESE, and from R-ASTR-ESE and KSC personnel working with conformal coating materials--are listed in table I.

3. Available Materials. Manufacturer's literature and test data retained by R-ASTR-ESE were reviewed for material sources and availability. More than 30 commercial coating materials were screened and 11 were found that were specifically formulated for thin film coating of ESE and which possibly could meet the established ideal requirements (see II. B. 2).

SECTION III. MATERIALS EVALUATION

A. MATERIALS EVALUATED

1. Castable Polyurethane Materials. Since all 3 polyurethane potting and molding materials now widely used as conformal coatings have the same basic characteristics, only 2 of the materials were evaluated.

2. Thin Film Forming Materials. Eleven of the thin film materials (see II. B. 3) were subjected to preliminary evaluation. Three of the 11 were selected for full evaluation because they exhibited more of the desired requirements than the other 8.

B. TEST SPECIMENS

Specimens selected for coating and testing were of the following 3 types:

1. Electrical. Specimens used for electrical testing were designed by R-ASTR-ESE especially for these electrical tests. The design is shown in figure 1.

2. Durability. Specimens used for durability testing were of the following 2 types:

   a. Actual service equipment. These specimens are printed circuit assemblies used in the type QS-11 scanning system and were pulled for testing because of problems encountered with this coated printed circuit assembly. Figure 2 shows this assembly design.

   b. Designed specimens. These specimens were designed especially for durability testing. The typical durability test specimen is shown in figure 3.

3. Low Temperature Flexibility. Specimens used for low temperature flexibility testing were designed by R-ASTR-ESE. This specimen is a panel of abraded aluminum with dimensions of 2.54 by 15.20 centimeters (0.1 by 6 inches) and 0.0508 to 0.0762 centimeter (0.02 to 0.03 inch) thick.

C. SPECIMEN PREPARATION

Specimens to be used for testing were prepared as follows:

1. All grease, oil, solder, flux, and other contaminates were removed from the specimens with alcohol (cleaning agent) and a soft brush.

2. All cleaning agent was removed with a jet of dry, filtered air.

3. The specimens were dried in an air-circulating oven at 50 to 60 degrees C for a minimum of 15 minutes.

4. The specimens were masked and conformal coated to a thickness of 0.0038 ± 0.0013 centimeter (0.0015 ± 0.0005 inch).

5. All specimens were cured as recommended by the manufacturer of his particular coating material.

D. TEST CONDITIONS

Unless otherwise specified for each individual test, the test specimens were tested at standard environmental conditions of 24 ± 2 degrees C and 50 ± 5 percent relative humidity.

E. TEST EQUIPMENT

Test equipment used by R-ASTR-ESE was that specified for each individual test (see section III. F).

F. TESTS AND TEST PROCEDURES

The tests and test procedures of III. F. 1 through III. F. 3 were carefully selected and monitored to give a true material evaluation in relation to the established material requirements specified in table I.

1. Handling Examination. The following material characteristics were observed during material preparation and specimen coating:

a. Viscosity. Viscosity was checked with a viscosimeter immediately after blending of the 2 mix parts (curing agent and urethane) was complete. Viscosimeter readings are recorded in table II.

b. Coagulation. Before blending, the curing agent and urethane of each material was stirred and examined with a stainless steel spatula to determine if crystalline solids were present that would require heat to dissolve. Results of the examination are recorded in table II.

c. Cavitation. During and after blending of the 2 mix parts, the materials were examined for the presence of entrapped CO_2 or air (bubbles) that would make degassing of materials necessary. Examination results are recorded in table II.

d. Application life. Application life is the period of time (beginning immediately after blending completion) the product being evaluated is suitable for application as a conformal coating. A product was considered suitable for application as long as viscosity was below 0.5 N.s/m^2 (500 centipoises). Viscosity of these products was measured with a viscosimeter, at intervals of 10 minutes until it exceeded the 0.5 N.s/m^2. This was considered the end of application life. Time was noted and is recorded in table II.

e. Cure temperature. Cure temperature is the temperature required for curing the material in an air circulating oven and was determined by the manufacturer of each material being evaluated. Specified material temperatures are recorded in table II.

f. Cure time. Coated specimens and button-type samples of each product were cured at room temperature for 30 minutes. They were then placed in air-circulating ovens and heated to 60 degrees C. Cure time for full cure was determined by the material manufacturer. After curing as specified by the manufacturer, the specimens were subjected to the adhesion test to determine if fully cured. Full cure time is recorded in table II.

g. Toxicity. Manufacturers certified each product to be nontoxic; however, during testing the materials were observed for unusual odors, asphyxia, and skin irritations. Observations are recorded in table II.

2. Electrical Tests.

a. Capacitance buildup (Q-factor). Five type (a) and 5 type (b) electrical test specimens (see figure 1)--1 uncoated and 4 coated for each of the 5 materials being evaluated--were Q-factor tested as follows:

(1) All specimens were stabilized at room temperature for 48 hours after coating.

(2) Extreme care was exercised during handling to keep fingerprints and other contaminants off the specimens.

(3) A Boonton Radio Q-Meter, model 190-A, was used for testing and the equipment was calibrated according to the manufacturer's procedure.

(4) Each specimen was subjected (at standard conditions) to frequencies of 50, 100, 150, and 200 megahertz as follows:

(a) The appropriate coil (accommodating the 50, 100, 150, and 200 megahertz frequency range) was connected to the coil terminals on the Q-meter and resonated to the required test frequency.

(b) The uncoated (control) specimen was connected to the last terminals on the Q-meter and resonated to the highest Q-factor reading (Q_1).

(c) The uncoated specimen was replaced with a coated specimen. The coated specimen was resonated to the highest obtainable reading (Q_2).

(d) The difference between Q_1 and Q_2 is the Q-factor of the coated specimen. The average Q-factor for each group of coated specimens is recorded in table III.

(5) After frequency testing at standard conditions, the specimens were conditioned in a Conrad Environmental Chamber (model FO-11-1-5) for 24 hours at 37 ± 2 degrees C and 95 ± 2 percent relative humidity, and were blotted dry after removal from the chamber.

(6) The specimens were retested as specified in III. F. 2. a(4), and again the average Q-factor for each group of coated specimens was determined (see table III).

b. Dissipation factor. The dissipation factor of each specimen subjected to Q-factor testing was calculated as the reciprocal of the average Q-factor obtained from each group of coated specimens. For example, the 0.0039 value for one castable material--specimen (a), figure 1--in table III is the reciprocal of the average Q-factor obtained from the 4 specimens coated with that particular material. Dissipation factors are recorded in table III.

c. Insulation resistance. Four type (a) and 4 type (b) specimens (figure 1) for each of the 5 materials being evaluated were insulation resistance tested as follows:

(1) The specimens were suspended in a chamber (at standard conditions) with glass hooks; voltage (less than breakdown) was applied to the specimen terminals with a Keithley Regulated Power Supply, model 241; and resistance of the specimens was measured with a Keithley Megohm Bridge, model 515. Measurements are recorded in table III.

(2) All specimens were exposed to salt fog (20 percent) in an Industrial Filter and Pump Manufacturing Company Chamber, model 411.C, for 16 hours; rinsed in running water at 37 ± 2 degrees C; and dried with lint-free cloth.

(3) The specimens were retested within an hour after being removed from the salt fog. Test results were noted and are recorded in table III.

d. Dielectric withstanding voltage. Four type (a) and 4 type (b) (figure 1) specimens for each of the 5 materials being evaluated were tested as follows:

(1) The specimens were subjected to voltage (at standard conditions) applied gradually at a rate of 500 volts per second until 1,000 volts alternating current were applied and maintained for 1 minute. Dielectric withstanding voltage was noted and measurements are recorded in table III. The voltage was applied and measured with an Associated Research Incorporated "Hypot," model 4501 M18.

(2) The same specimens were subjected to 5 continuous humidity condition cycles as follows:

(a) For 2 hours, the specimens were in a humid (90 to 95 percent) conditioning chamber, with the temperature gradually increased from 24 ± 2 degrees C to approximately 71 degrees C throughout the 2-hour period.

(b) The hot-humid condition was maintained for an additional 6 hours and then the temperature was gradually lowered to the original temperature throughout a 16-hour period.

(3) After temperature-humidity cycling, the specimens were kept at standard conditions for an additional 24 hours before retesting.

(4) Dielectric withstanding voltage was again measured as specified in (1). Test data is recorded in table III.

3. Physical Tests.

a. Compatibility. Four, either (a) or (b), specimens (see figure 1) for each of the 5 materials being evaluated were subjected to compatibility testing as follows:

(1) The specimens were exposed to 10 cycles of temperature humidity conditioning in a Conrad Environmental Chamber, model FP-11-1-5, as specified in III. F. 2. d.

(2) Throughout the conditioning process, a 100 volt direct current potential was applied to the terminals of each specimen with a Keithley Regulated Power Supply, model 241.

(3) During voltage application, a Fluke Differential Voltmeter, model 883AB, was used to assure consistent voltage readings and a Keithley Microvolt Ammeter, model 203A, was used to detect any current leakage.

(4) Current and voltage were monitored continuously during testing, and after testing completion all specimens were examined under 20 power magnification for signs of chemical reaction or electrolytic ionization (corrosion). Results are recorded in table II.

b. Specific gravity. A 1 to 5 gram cured piece of each of the 5 materials being evaluated was used for this test. The test was performed as follows:

(1) The cured piece of each material was weighed in air on an analytical balance and weight was recorded as W_1.

(2) A piece of wire (0.1016 millimeter--0.004 inch--diameter) was attached to one arm of the balance and weighed with the free end suspended in distilled water. This weight was recorded as W_2.

(3) The wire was marked at water level, removed from the water, and the submerged portion was used for tying to each of the weighed specimens (W_1). Each specimen and wire were weighed. Each weight was recorded as W_3.

(4) All weights were made to the nearest tenth (0.1) of a milligram, and the specific gravity of each material was calculated to the nearest 0.001 as follows:

$$\text{Specific gravity} = \frac{W_1}{W_1 - (W_3 - W_2)} \times 0.9971$$

Specific gravity calculations are recorded in table II.

c. Fungus resistance. Since all 5 materials being evaluated were two-part urethanes and urethane polymers do not support fungus growth, no cultural tests were performed. Manufacturers of the 5 materials agreed to certify that the final material (including additives) will not support fungus growth when subjected to anticipated conditions of printed circuit use.

d. Adhesion. One type (a) and 1 type (b) specimen (figure 1) for each of the 5 materials being evaluated were tested for coat adhesion. These specimens had been used for the electrical tests and were not damaged. A sharp knife was used to cut through the coating around an area approximately 0.635 centimeter (0.211 inch) wide and 2.54 centimeters (0.1 inch) long that might be peeled away. The knife was held at an angle of approximately 30 degrees and attempts were made to peel the coating from the board. Results are recorded in table II.

e. Low temperature flexability. Three coated specimens (see III. B. 3) of each of the 5 materials being evaluated was low temperature flexibility tested as follows:

(1) All specimens were conditioned at minus 55 ± 2 degrees C for 1 hour.

(2) The conditioning temperature was maintained while each specimen was bent individually around a 2.54 centimeter (0.1 inch) diameter mandrel.

(3) Each specimen was examined under ultraviolet light for cracks or crazing. The results are recorded in table II.

f. Durability. Six coated specimens as shown in figure 2 (actual equipment), and 6 coated specimens as shown in figure 3 (typical) for each of the 5 materials being evaluated were durability tested as follows:

(1) Each specimen was secured in a special fixture (figure 4) and vibrated, on a Ling Amplifier MB Electronics Vibration Table, model C 10 VB, in 3 mutually perpendicular planes at a total excursion of 0.1524 centimeter (0.06 inch) double amplitude displacement. (The holding fixture is designed for relocation of the specimen to attain the 3 directions.)

(2) The sinusoidal frequency was gradually increased from 10 to 2,000 hertz throughout a period of 20 minutes for each direction vibrated, making 160 minutes total vibration.

(3) Actual functions of the specimens were simulated and monitored with a Visicorder, model 1108-206700HK (as shown in figure 5), throughout each series of vibration.

(4) Test results are recorded in table II.

g. Fluorescence. All tested specimens were subjected to ultraviolet (black) light to determine quality of fluorescence in coating applied to the printed circuit assemblies. Flourescence of the coating materials indicates the following:

(1) Even glow on all surfaces indicates uniform coating.

(2) Splotches of glow indicate nonuniform coating.

(3) Dark spots indicate voids.

(4) Glowing rings with dull centers indicate bubbles.

(5) Dark points indicate pinholes.

(6) Large elongated glowing areas indicate runs.

(7) Large dark areas indicate no coating.

(8) Small intensely glowing areas indicate lumps.

Fluorescence quality of each coating material is recorded in table II.

SECTION IV. DATA ANALYSES

A comparative analysis of the 5 materials selected for evaluation can be made by comparing data in tables II and III. The castable polyurethane materials are those originally designed for potting and molding and adapted for use as conformal coating; however, the thin film materials were designed specifically for thin film conformal coating of ESE. All 5 materials selected for full evaluation are 2-part polyurethanes. Monopart coating materials are available; but, the 2-part urethanes have more of the desirable processing characteristics (see table 1) than do the monopart materials. For this reason, only the 2-part urethanes were fully evaluated.

Physical and handling test results are shown in table II. These results indicate that both physical and handling characteristics of the thin film materials are far superior to those of castable polyurethane. Before blending, the 2 parts were checked for coagulation or crystalline solids. These crystals that require heat to dissolve were present in the castable materials but were not present in the thin film materials (see table II).

After liquifying all crystalline solids, the 2 parts were blended together and checked for bubble formations that would require degassing. A heavy concentration of bubble formations were present in the castable materials and none were present in the thin film materials (see table II). Therefore, the thin film materials required no degassing but the castable materials required degassing for approximately 20 minutes.

After complete blending and degassing, initial viscosity of the prepared coating material was checked with a viscosimeter. Readings for the castable materials were 10 and 22 $N.s/m^2$ (10,000 and 22,000 centipoises) whereas readings for thin film materials were 0.48, 0.025, and 0.150 $N.s/m^2$ (480, 25, and 150 centipoises)--see table II. Low viscosity of the thin film materials results in easier application. It can be applied by the dip and brush process as well as by spraying; and the thin film spray process does not require costly proprietary spray equipment. Also, the extensive and costly masking process can be greatly reduced because the entire board (except occasional adjustable potentiometer or piston type capacitors) can be dip or brush coated, up to the contact edge, to approximately 0.00508 centimeter (0.002 inch) thick without masking. This thin coating on the cut edges of printed circuit boards is advantageous because it seals out moisture and the increase of board thickness is negligible. Castable materials, feasibly, cannot be applied thin enough to prevent greatly increased thickness and allow the boards to fit into standard cabinets. Therefore, the expensive masking of all edges is necessary before coating with the castable materials but is not necessary when coating with the thin film materials.

The most significant advantage of thin film over castable materials from the standpoint of mass production is increased application life and decreased cure time and temperature. Application life was increased from 30 to 45 minutes for castable materials to 8 hours for thin film materials. Cure time was decreased from approximately 24 to 30 hours at 60 degrees C to approximately 2 hours at 60 degrees C. This increased application life and decreased cure time mean lower costs to the manufacturer and NASA in the form of better coated and sealed boards at lower material cost, less oven time and power consumption, less expenditure for curing ovens and personnel, and less space required to perform the same amount of work.

All 5 materials were approximately equal as far as toxicity, compatibility, specific gravity, adhesion, low temperature flexibility, and durability are concerned but are not equal in fluorescence (see table II). The castable polyurethane materials were nonfluorescent, therefore, coating uniformity could not be determined under black light. On the other hand, the thin film materials were highly fluorescent and coating uniformity could be evaluated with great accuracy under black light.

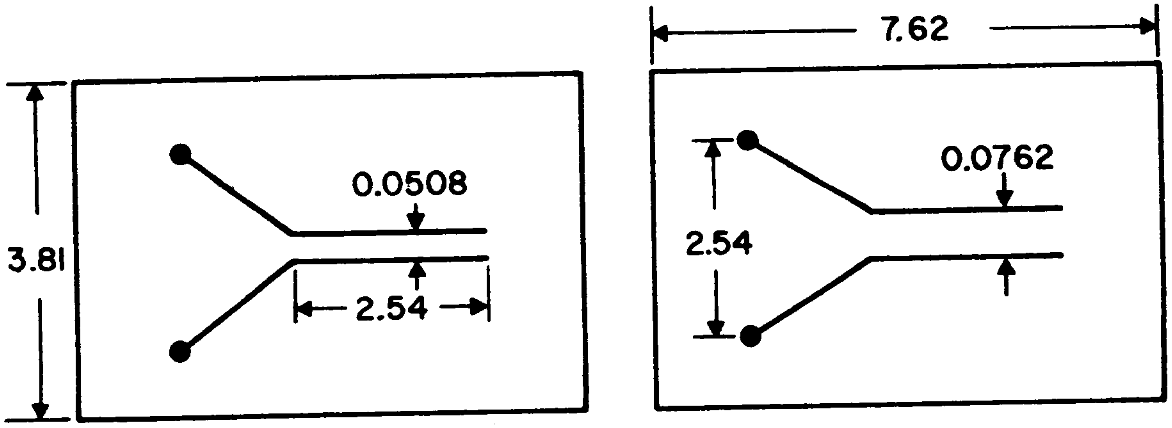
Durability testing (vibration in 3 mutually perpendicular planes at a total excursion of 0.1524 centimeter--0.06 inch--double amplitude displacement for 120 minutes total vibration) proved the 0.00508 centimeter (0.002 inch) thin film coating adequately supported components through the required vibration range for ESE.

Electrical test data covering Q-factor, dissipation factor, insulation resistance, and dielectric withstanding voltage are included in table III. These data indicate that dissipation factor and dielectric withstanding voltage are approximately equal for all coated specimens tested, whereas, Q-factor and insulation resistance at standard conditions and after environmental conditioning are greatly improved in specimens coated with the thin film materials.

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

This report has shown that there are valid production and performance problems associated with castable polyurethane conformal coated electrical support equipment which can be eliminated by using thin film conformal coating materials designed specifically for coating ESE rather than the castable polyurethane materials presently being used.

Testing and comparative analysis of the 5 materials showed that the thin film materials have physical, handling, and electrical characteristics far superior to those of the castable polyurethanes. The superior physical and handling characteristics will eliminate most problems associated with production and quality, and the superior electrical characteristics will eliminate most problems associated with the electrical performance of coated printed circuit assemblies. The elimination of problems not only will reduce production time, but also will substantially reduce production costs and will provide a higher degree of performance reliability. Therefore, it is recommended that thin film materials be qualified for use as conformal coating of ESE.



NOTES:
1. Dimensions are in centimeters.
2. Specimens were fabricated in accordance with Standard MSFC-STD-154.
3. Coating is 0.0038 ± 0.0013 centimeter (some uncoated).

FIGURE 1. SPECIMEN DESIGN FOR ELECTRICAL TESTS.

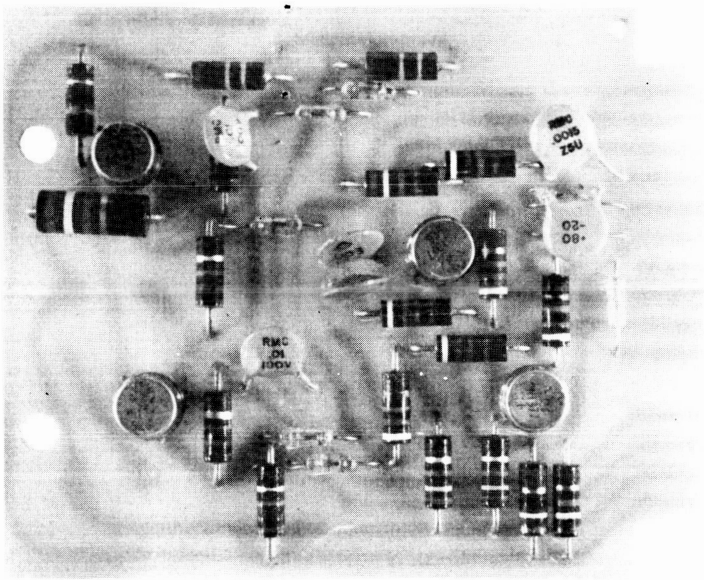


FIGURE 2. DURABILITY TEST SPECIMEN FROM QS-11 SCANNING SYSTEM

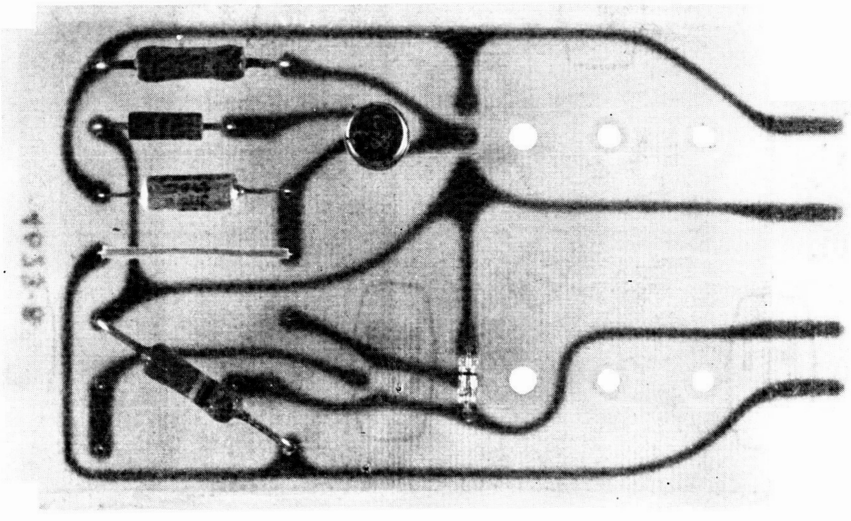


FIGURE 3. DURABILITY TEST SPECIMEN, TYPICAL,

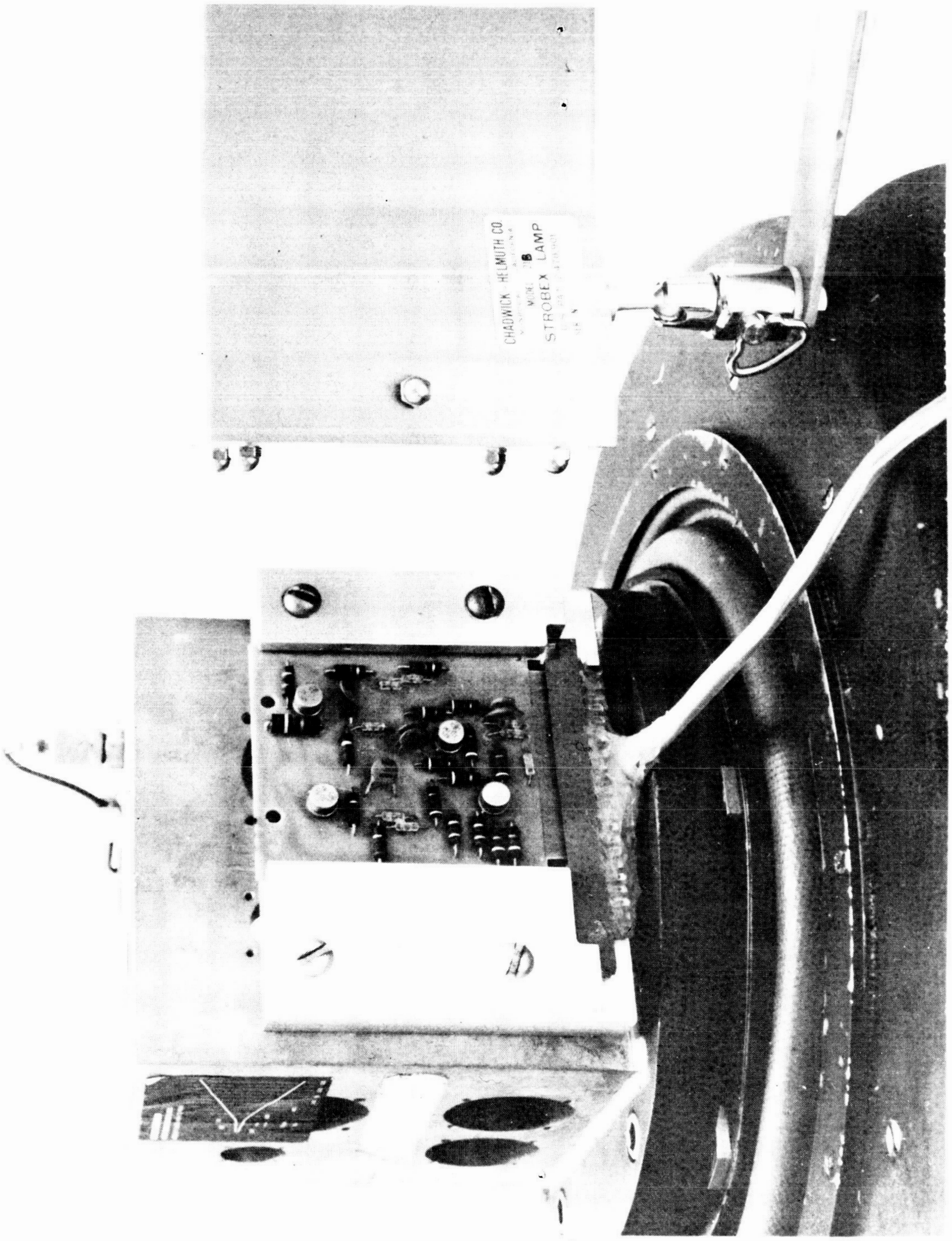


FIGURE 4. DURABILITY TEST FIXTURE.

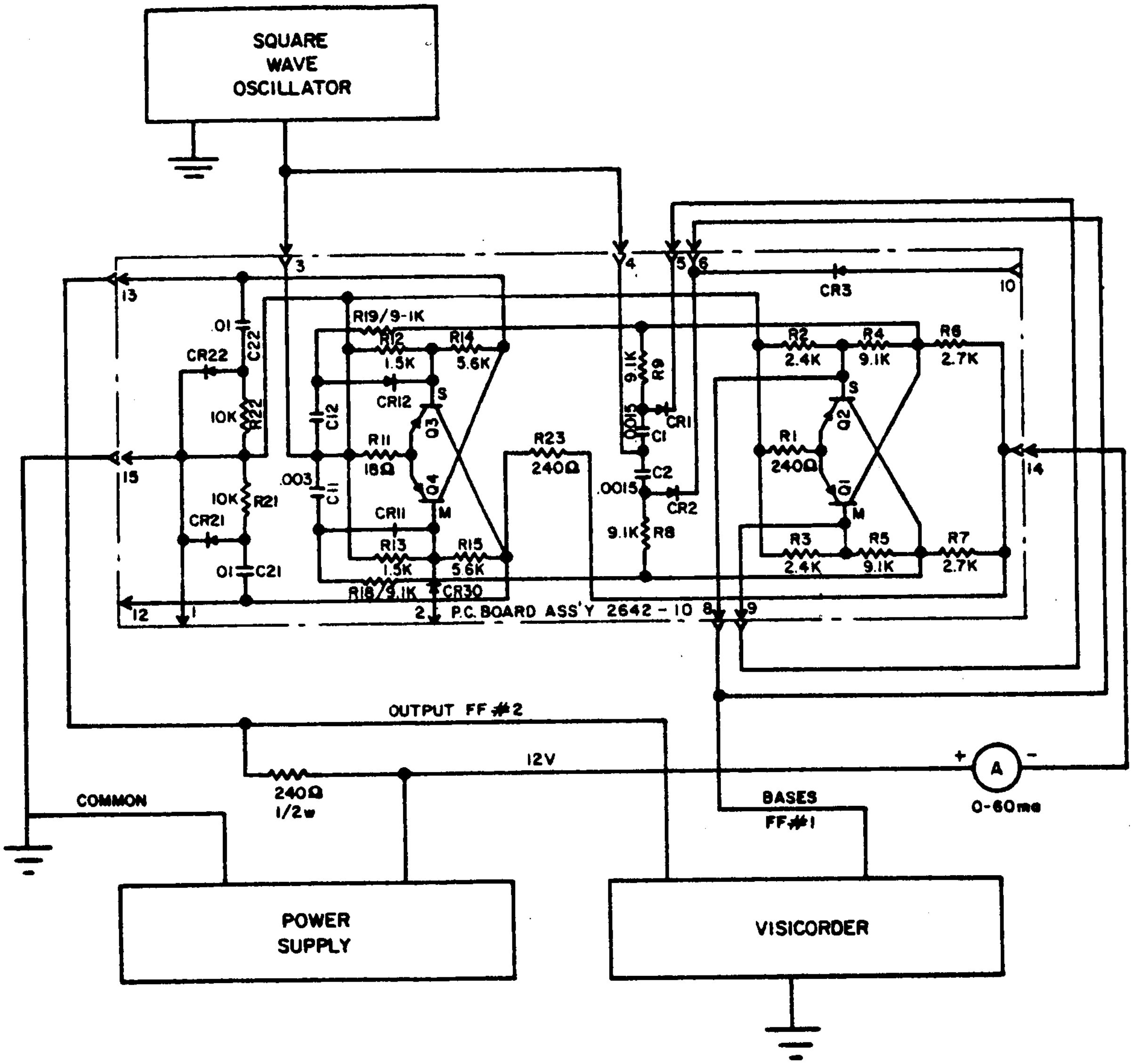


FIGURE 5. DURABILITY TEST HOOKUP.

TABLE I. IDEAL REQUIREMENTS FOR COATING MATERIALS

Characteristics or Properties	Requirements
Handling	
Viscosity	5 N.s/m^2
Coagulation or crystallization	None that require heat to liquify
Cavitation	No bubble formation
Application life	4 hours minimum at standard conditions
Cure temperature	58 ± 2 C maximum
Cure time	8 hours maximum
Toxicity	No special handling precautions required
Application	Capable of being applied by dip, brush, or conventional spray techniques
Performance	
Capacitance buildup (Q-factor)	Least change of Q-factor between uncoated and coated circuitry
Dissipation factor	0.09 maximum
Insulation resistance	10^{12} ohms minimum at standard conditions; 2 x 10^{11} ohms in salt fog
Dielectric withstanding voltage	No breakdown; leakage of 5 microamperes maximum
Compatibility (chemical)	No damage to board, circuit, or components
Specific gravity	1.25 maximum
Fungus	Nonsupporting
Adhesion	Will not peel from objects of associated use
Low temperature flexibility	No cracking or crazing
Durability	No cracking or lifting of components, and no broken leads or solder joints
Appearance	
Formulation	Dyes, flame retardants, and fungicides incorporated
Color	Red, blue, or green (transparent)
Fluorescence	Dye must show flaws under ultra-violet

TABLE II. HANDLING AND PHYSICAL TEST DATA

Test	Castable Polyurethane Materials		Thin Film Materials		
	1	2	1	2	3
Handling					
Viscosity ($N.s/m^2$)	10.0	22.0	0.48	0.025	0.150
Coagulation	Solids present	Solids present	None	None	None
Cavitation	Bubbles	Bubbles	None	None	None
Application life (hours)	1	0.5	8	5	8
Cure Temperature (°C)	60	60	60	60	60
Cure Time (hours)	24 to 30	24 to 30	1.5	1	2
Toxicity	Nontoxic	Nontoxic	Nontoxic	Nontoxic	Nontoxic
Physical					
Compatibility	Noncorrosive	Noncorrosive	Noncorrosive	Noncorrosive	Noncorrosive
Specific Gravity	1.05	1.07	1.02	1.0	0.95
Adhesion	Good	Good	Excellent	Excellent	Excellent
Low Temperature Flexibility	No defects	No defects	No defects	No defects	No defects
Durability *	No defects	No defects	No defects	No defects	No defects
Fluorescence	Nonfluorescent	Nonfluorescent	Highly fluorescent	Highly fluorescent	Highly fluorescent

* Uncoated specimens had defects.

TABLE III. ELECTRICAL TEST DATA

Test	Condition		Castable				Thin Films					
			1		2		1		2		3	
	Standard	Other*	a	b	a	b	a	b	a	b	a	b
Q-factor (Difference)	50 Hz		62.50	53.75	40.00	72.50	9.50	4.50	2.13	2.50	16.00	7.50
	100 Hz		45.00	33.75	32.00	34.00	6.20	4.25	1.75	1.50	11.00	7.50
	150 Hz		76.25	65.00	48.00	66.00	9.25	4.75	2.50	2.25	28.00	15.00
	200 Hz		50.00	51.25	38.00	66.00	6.75	9.00	2.00	1.50	38.50	25.00
		50 Hz	77.50	72.50	54.00	72.00	11.25	18.75	5.75	7.50	18.00	
		100 Hz	52.50	53.75	34.00	45.00	12.25	10.75	4.50	5.00	15.00	
		150 Hz	83.75	72.50	62.00	76.00	32.50	18.75	10.00	13.25	31.00	
		200 Hz	63.50	51.25	56.00	76.00	12.50	20.00	5.75	15.50	38.00	
Dissipation Factor	50 Hz		0.0039	0.0040	0.0039	0.0040	0.0033	0.0047	0.0032	0.0031	0.0035	0.0032
	100 Hz		0.0039	0.0041	0.0040	0.0040	0.0035	0.0052	0.0035	0.0034	0.0039	0.0036
	150 Hz		0.0056	0.0062	0.0052	0.0053	0.0043	0.0063	0.0034	0.0040	0.0049	0.0042
	200 Hz		0.0111	0.0131	0.0088	0.0091	0.0074	0.0106	0.0074	0.0044	0.0098	0.0071
		50 Hz	0.0035	0.0040	0.0038	0.0040	0.0034	0.0032	0.0031	0.0033	0.0038	
		100 Hz	0.0037	0.0046	0.0040	0.0040	0.0035	0.0035	0.0034	0.0033	0.0040	
		150 Hz	0.0050	0.0056	0.0053	0.0056	0.0045	0.0043	0.0042	0.0040	0.0051	
		200 Hz	0.0087	0.0101	0.0096	0.0107	0.0082	0.0077	0.0076	0.0074	0.0090	
Insulation Resistance (Ohms)	- -		7.9×10^{10}	2.2×10^{11}	6.2×10^{11}	4.1×10^{11}	6.3×10^{14}	6.5×10^{14}	2.4×10^{14}	2.1×10^{14}		5.2×10^{14}
		- -	1.1×10^{10}	9.3×10^{9}	1.3×10^{10}	3.8×10^{10}	6.1×10^{12}	4.0×10^{12}	3.2×10^{12}	3.0×10^{12}		1.9×10^{12}
Dielectric Withstanding Voltage (μa)	- -		5	5	5	5	5	5	5	5		5
		- -	5	5	5	5	5	5	5	5		5

* Environmental conditioning other than at standard conditions.

ESE-E-55
October 10, 1966

APPROVAL

EVALUATION AND COMPARATIVE ANALYSIS OF CONFORMAL COATING MATERIALS

By

Equipment Production and Evaluation Section

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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