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NASA TECHNICAL
MEMORANDUM

NASA TM X-53181

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DECEMBER 16, 1964

NASA TM X-53181



EVALUATION OF POLYMERIC MATERIALS FOR ELECTRONIC PACKAGING

by BOBBY W. KENNEDY
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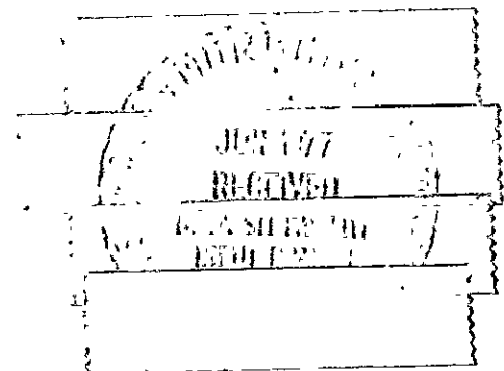
(NASA-TM-X-53181) EVALUATION OF POLYMERIC
MATERIALS FOR ELECTRONIC PACKAGING, (NASA)
43 p

N77-79077

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ABSTRACT

Certain potting and conformal coating materials were contributing to the failure of critical glass-sealed components and solder joints in cordwood modules and on printed circuit boards. The cause of these failures was determined to be differences in coefficients of thermal expansion for materials. Analysis indicated the necessity of selecting materials with a lower coefficient of thermal expansion for potting cordwood modules and changing from a hard, rigid epoxy to a soft, flexible polyurethane for printed circuit board conformal coating.

Of the four potting materials tested, Emerson and Cuming's Stycast 1090 epoxy was selected for potting cordwood modules.

Three of the coating materials were too thin to support components; therefore, no further testing of these materials is anticipated. However, these materials may be used when a thin protective coating is needed and when component support is not a problem.

Products Research-1538 polyurethane material is recommended and is being used for coating printed circuit boards; however, in high frequency circuits, an epoxy may be used after encapsulating the component with vinyl sleeving to prevent RF losses.

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By

Bobby W. Kennedy

PILOT MANUFACTURING DEVELOPMENT BRANCH
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TECHNICAL MEMORANDUM X- 53181

EVALUATION OF POLYMERIC MATERIALS FOR ELECTRONIC PACKAGING

SUMMARY

Rigid potting and coating materials, because of differences in coefficients of thermal expansion, cause failure of delicate electronic components.

For potting, materials having a coefficient of thermal expansion nearer that of the electronic module were evaluated for various properties. Emerson and Cuming's Stycast 1090 epoxy proved superior to other materials tested.

For conformal coating of printed circuit boards, flexible polyurethane coatings were evaluated. Products Research PR 1538 is recommended for this purpose.

SECTION I. INTRODUCTION

The coating or filling of electronic equipment is as important as the design of the circuit. Waxes and other compounds were used as fillers in early radio and electronics applications. With today's integrated circuitry and thin film and semiconductor devices, the use of materials for electronic packaging has advanced rapidly. The expense of using these polymeric materials has gradually decreased as research and competition have made more and better products available.

There are several methods of using polymeric materials for electronic packaging. Embedment is the complete encasement of an electronic assembly or component, usually using a mold to ensure that the item is completely surrounded by the encasing material. Conformal coating, or encapsulation, is the application of a coating that actually conforms to the shape of the coated item. The coating usually consists of a high-viscosity plastic that will cure from a liquid to a solid at near room temperature and low pressure. The plastic material is applied by dipping, brushing, or spraying.

The primary purpose of embedding, conformal coating, and other electronic packaging techniques is protection against dust, moisture, and other foreign atmospheric materials, which might be detrimental to the operation of some electronic components. The use of properly selected plastics also provides better dielectric strength and greater insulation resistance.

Some materials used in electronic packaging tend to ruggedize or increase the mechanical strength of the coated item and protect it against vibration, shock, and other stresses. Ruggedizing helps eliminate the need for mounting hardware, such as terminal strips or lugs, thus reducing weight while increasing the strength of the assembly.

Plastic packaging materials can be formulated to possess various degrees of flexibility or rigidity, ranging from rubber-like silicones to rigid epoxies which display tremendous tensile strength and hardness.

Many different plastic packaging materials are presently available and each of these materials differs sufficiently in properties (heat resistance, flexibility, impact strength, etc.) or composition (acid catalyst, etc.) to merit consideration for distinct applications. Some of these materials are polyesters, urethane resins, epoxy resins, RTV silicone rubbers, solventless silicones, silicone gels, polysulfide rubbers, phenolic resins, polystyrene resins, polybutadiene resins, and hydrocarbon resins.

Two of the most frequently used synthetic packaging materials are urethane resins and epoxy resins. Urethanes are often referred to as polyether diisocyanates, polyester diisocyanates, polyurethanes, isocyanates, and diisocyanates, because of their chemical compositions. Some classes of cured urethanes are called urethane elastomers, urethane rubbers, or urethane foams, and possess properties that are very similar to those of rubber. Urethanes display excellent electrical and mechanical properties, as well as high abrasion resistance, and can be easily formulated into end products of different densities.

Uncured epoxy resins are formed by combining two chemicals: epichlorohydrin and diphenylolpropane. Epoxy resin is cured by adding one of many different types of curing agents and then applying heat. The amount and type of curing agent used, and the amount of heat applied during curing, determine many of the properties of the cured epoxy material.

Some of the advantages of epoxies over other polymeric packaging materials are:

A. Epoxies have adhesive properties better than those of most other packaging materials.

B. Curing of epoxies is not dependent upon air.

C. Epoxies display extremely high resistance to environmental extremes such as humidity and temperature.

D. Shrinkage of epoxies is very low.

Some of the disadvantages of using epoxy resins as packaging materials are odors, toxicity, and high thermal coefficient of expansion when the resins are not highly filled with inorganics.

Embedment of cordwood modules presents one of the most difficult packaging problems in the Saturn systems. Cordwood modules cannot absorb the high thermal expansion of most potting materials because of the high component density. In an effort to eliminate thermal expansion as a cause of failure in cordwood modules, a test program was initiated to evaluate several compounds for electrical and physical properties, application and cure characteristics, and the effect on components and solder joints. Test results indicated that potting with a highly filled epoxy having a low coefficient of thermal expansion was most feasible.

Because some conformal coatings were contributing to the failure of critical glass-sealed components by causing cracking during thermal cycling, an accelerated test program was initiated to determine the mechanics of fracture, and to evaluate plastics so that a satisfactory coating could be recommended. On the basis of physical, electrical, and environmental test results, the elastomeric polyurethane coating appeared to be the most promising.

Appreciation is expressed to Mr. I. A. Wagner and Mr. Bob Porter* of the Pilot Manufacturing Development Branch for conducting some of the tests discussed in this report.

*Brown Engineering Co.

SECTION II. EVALUATION OF POTTING COMPOUNDS FOR CORDWOOD DESIGNED MODULES

A. GENERAL

Plastic embedment material is an integral part of the system design and should be considered at the earliest opportunity to avoid possible delays and failures in the final packaging of the equipment.

No single resin system can be used for every type of application because of the broad range of equipment, components, design considerations, and final environment the package must withstand.

Three types of failure caused by differences in the coefficients of thermal expansion have been observed in cordwood modules:

1. Fracture of solder joints.
2. Fracture of glass components.
3. Leads pulled out of components.

In an effort to eliminate thermal expansion as a cause of failure of cordwood modules, three approaches were considered.

1. Potting with a flexible material.
2. Protecting the components with a flexible material before potting.
3. Potting with a plastic having a low coefficient of expansion.

Of these three methods, potting with a highly-filled epoxy having a low coefficient of expansion appeared to be the most feasible.

Two different tests were performed on materials used as module potting compounds: test procedure I was the testing of electrical and physical properties of these materials, while test procedure II was the testing of modules potted with four different compounds.

B. TEST PROCEDURE I

Electrical and Physical Properties. Electrical and physical characteristics of Stycast 1090, Stycast 2651, Scotchcast XR 5038, and IBM LDT-7A were obtained by testing to FED-STD-406. Physical properties of these materials were determined by testing in accordance with MIL-I-16923D (Table I).

C. TEST PROCEDURE II

1. Effect of Thermal Cycling on Solder Joints of Cordwood Modules.

Thirty cordwood modules 2.5 by 1.9 by 1.2 cm and thirty cordwood modules 2.5 by 1.9 by 2.5 cm were constructed using four components (one component located at each corner). The modules were potted with Stycast 1090 and Stycast 2651 (using Catalyst 11), IBM LDT-7A, and Scotchcast XR-5038, and cured overnight at 60°C. The modules were examined for broken solder joints and then subjected to five temperature cycles on the following schedule: 1.0 hour at -50°C, 0.5 hour at +25°C, 1.0 hour at +100°C, and 0.5 hour at +25°C. The modules were then examined with a 15-power microscope for broken solder joints. Microscopic examination of the cordwood modules potted in Stycast 1090 and Stycast 2651 showed no evidence of fracture in any of the 240 solder joints.

2. Effect of Thermal Cycling and Mold Shrinkage on Components.

Sixty cordwood modules were constructed and potted in the manner listed in Table II (see Figure 1 for cordwood module design). Five components (one located in each corner and one in the center) were used with each module. Component values were checked before and after potting, using a curve tracer for diodes and a capacitance bridge for capacitors. Five temperature cycles and inspection were performed as described in paragraph C. 1. Small variations in breakover voltages for diodes and capacitance changes in glass capacitors were observed. These deviations were minor and would not affect circuit operation.

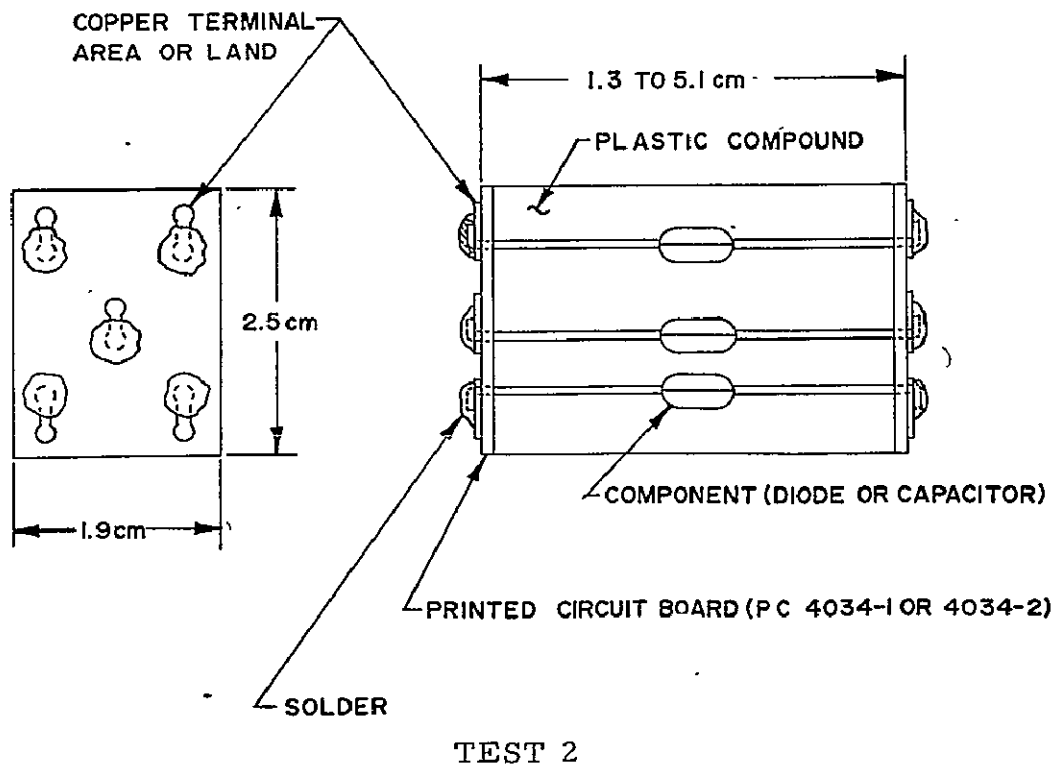
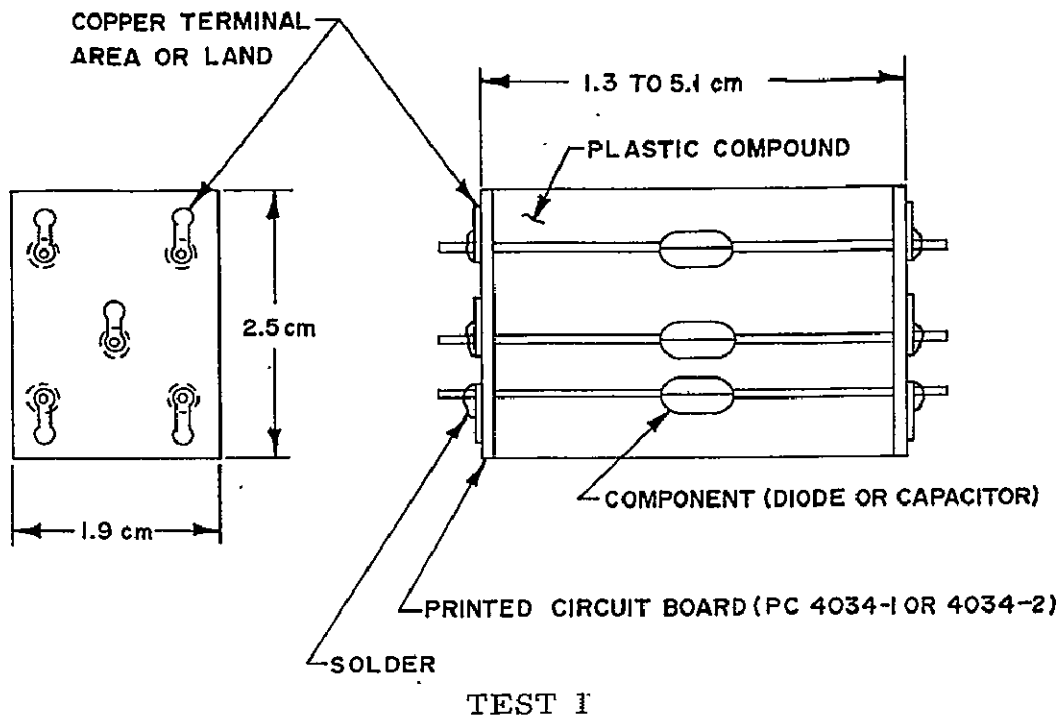


FIGURE 1. CORDWOOD MODULE DESIGN

Table I. Electrical and Physical Properties

Properties	Scotchcast XR-5038	Stycast 1090	Stycast 2651	IBM LDT-7A
Volume Resistivity (ohm/cm @ 25°C)	4.5×10^{14}	21×10^{12}	5×10^{14}	8×10^{14}
Dielectric Constant (@ 10^2 Hz)	4.3	3.3	4.4	3.0
Dielectric Strength (Volts/cm)	1.38×10^5	1.18×10^5	1.77×10^5	1.36×10^5
Dissipation Factor (@ 10^2 Hz)	0.034	0.015	0.010	0.046
Coefficient of Linear Thermal Expansion (per °C)	75×10^{-6}	35×10^{-6}	38×10^{-6}	80×10^{-6}
Thermal Conductivity (J/m/s °K)	0.25	0.115	0.405	0.125
(Btu/in/ft ² /hr/°F)	1.8	0.8	2.8	0.87
Hardness (Shore D Scale)	85	80	80	75
Moisture Absorption (% wt. gain after 24 hr at 25°C immersed in water)	0.5	0.1	0.1	0.5
Specific Gravity	1.46	0.78	1.55	0.92

Table II. Test Modules

Test No.	No. Modules	Potting Material	No. Components	Module Size (cm)
1	5	Stycast 2651	5	2.5 by 1.9 by 1.3
2	5	Stycast 2651	5	2.5 by 1.9 by 2.5
3	5	Stycast 2651	5	2.5 by 1.9 by 5.1
4	5	Stycast 1090	5	2.5 by 1.9 by 1.3
5	5	Stycast 1090	5	2.5 by 1.9 by 2.5
6	5	Stycast 1090	5	2.5 by 1.9 by 5.1
7	5	IBM LDT-7A	5	2.5 by 1.9 by 1.3
8	5	IBM LDT-7A	5	2.5 by 1.9 by 2.5
9	5	IBM LDT-7A	5	2.5 by 1.9 by 5.1
10	5	Scotchcast XR-5038	5	2.5 by 1.9 by 1.3
11	5	Scotchcast XR-5038	5	2.5 by 1.9 by 2.5
12	5	Scotchcast XR-5038	5	2.5 by 1.9 by 5.1

3. Effect of Thermal Expansion of Potting Compounds on Three Lengths of Cordwood Modules.

a. Module construction. Modules were made in groups of three different lengths (1.3, 2.5, and 5.1 cm) for testing the thermal expansion effect of the potting compounds. Diodes and capacitors were assembled into 175 modules (Fig. 1) and potted with the following compounds:

- (1) Stycast 1090, a silica microballoon filled epoxy resin
- (2) Stycast 2651, an epoxy resin with a mica filler
- (3) IBM LDT-7A, a phenolic microballoon, mica, and colloidal silica filled epoxy resin cured with a modified polyamine
- (4) Scotchcast XR-5038, a filled epoxy resin system.

b. Inspection. After assembly, the modules were visually inspected and the components were checked for electrical continuity. The modules containing the diodes were checked on a transistor-curve tracer, the capacitor modules were checked on an impedance bridge, and the readings were recorded.

c. Thermal shock. The modules were subjected to five thermal-shock cycles (Fig. 2) with each cycle consisting of four one-hour periods. The first cycle temperature range was from -45 to $+90^{\circ}\text{C}$. The low temperature of each succeeding cycle was 10°C lower than that of the preceding cycle, reaching -85°C during the last cycle. The high temperature of each succeeding cycle was 15°C higher than that of the preceding cycle, reaching $+150^{\circ}\text{C}$ during the last cycle.

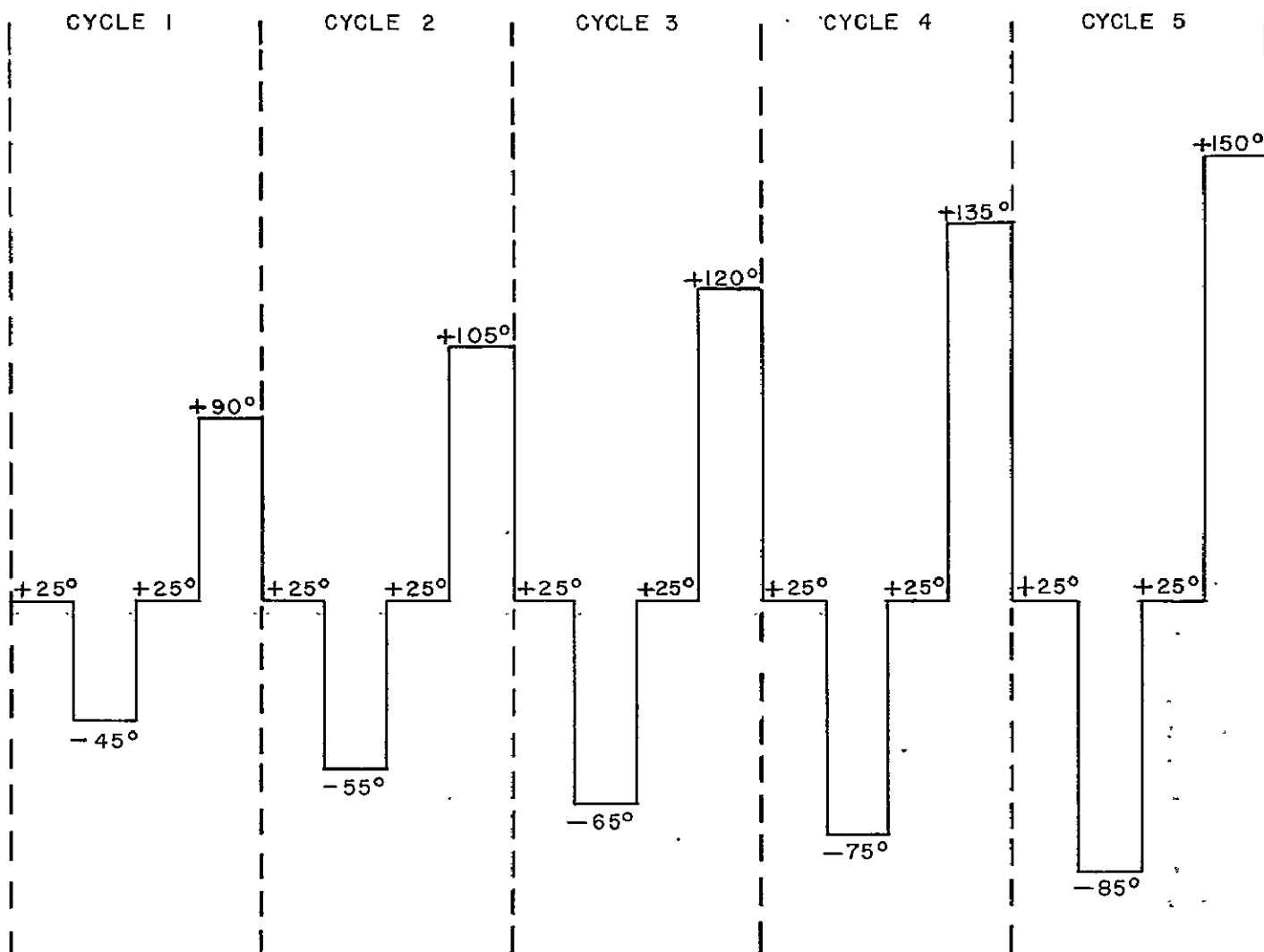
d. Results. After each thermal-shock cycle, the modules were inspected as they were inspected after assembly. :

(1) Stycast 1090. All groups of 1.3, 2.5, and 5.1-cm diode and capacitor modules potted with Stycast 1090 remained entirely free from broken soldered connections; component values did not change throughout the five thermal-shock cycles in which the final extreme temperatures were -85°C and $+150^{\circ}\text{C}$.

(2) Stycast 2651. The 1.3, 2.5, and 5.1-cm diode modules and the 1.3-cm capacitor modules potted with Stycast 2651 were free from broken soldered connections throughout the five thermal-shock cycles.

(3) IBM LDT-7A. The 1.3-cm diode and capacitor modules potted with IBM LDT-7A were free from broken soldered connections throughout the five thermal-shock cycles, with one exception. One of the 1.3-cm diode modules showed broken soldered connections after the final (fifth) thermal-shock cycle.

(4) Scotchcast XR-5038. All modules potted with Scotchcast XR-5038 developed broken solder connections during the thermal-shock cycles.



NOTES

1. TEMPERATURES ARE IN CENTIGRADE.
2. EACH TEMPERATURE LEVEL WAS HELD ONE HOUR.

FIGURE 2. THERMAL-SHOCK CYCLING

SECTION III. EVALUATION OF CONFORMAL COATINGS FOR PRINTED CIRCUIT (PC) BOARDS

A. INTRODUCTION

Using Hysol 12-005 and 12-007 epoxy as conformal coatings, a complete series of thermal shock tests (-50 to +85°C) was conducted on glass diodes (1.0 to 2.5 cm in diameter) and transistors. It became evident that the majority of failures occurred at temperatures below +25°C and were caused by the following combination of factors (Fig. 3):

1. Strong adhesive bond of the epoxy coating to the glass diode
2. Large differential coefficient of expansion between the epoxy and the glass
3. Rigid nature of the coating at low temperatures
4. Residual and transient thermal stresses present in the glass
5. The thermal conductivity of conformal coating materials is poor, causing a momentary temperature differential between the top and bottom halves of the diodes. This results in a concentration of thermal stresses at the coating-glass interfaces and causes the diodes to crack.

After determining the above mode of failure of the glass, these basic requirements and parameters were established for a conformal coating:

1. Transparency
2. Adhesion to substrate
3. Compatibility with PC board materials and components
4. Excellent shock and vibration properties
5. Good electrical properties under high humidity conditions
6. Noncorrosiveness
7. Mechanical strength

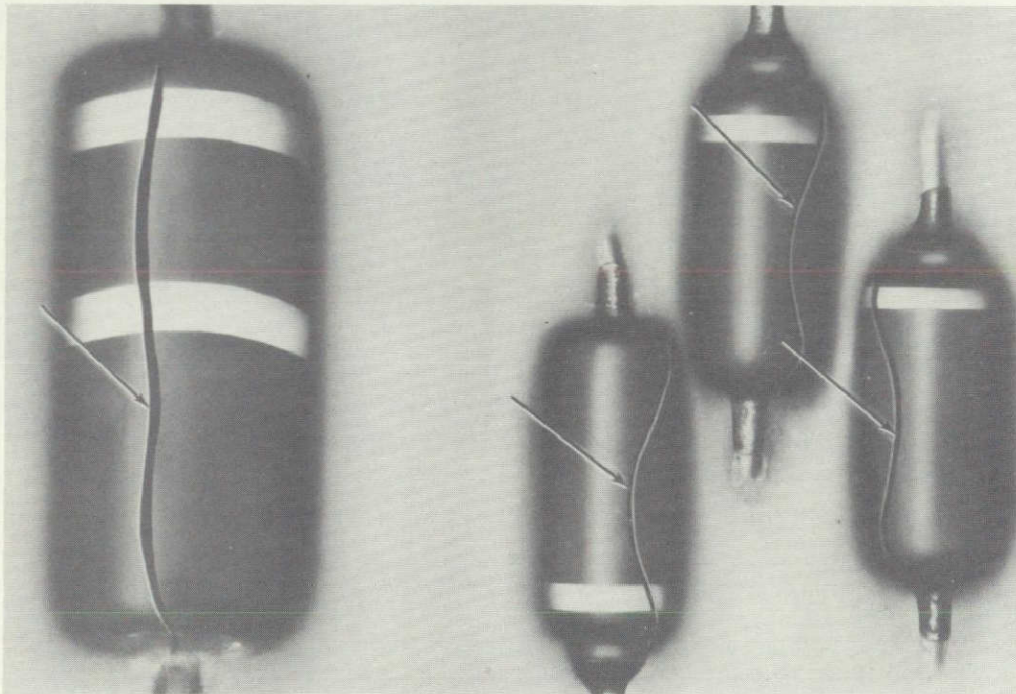
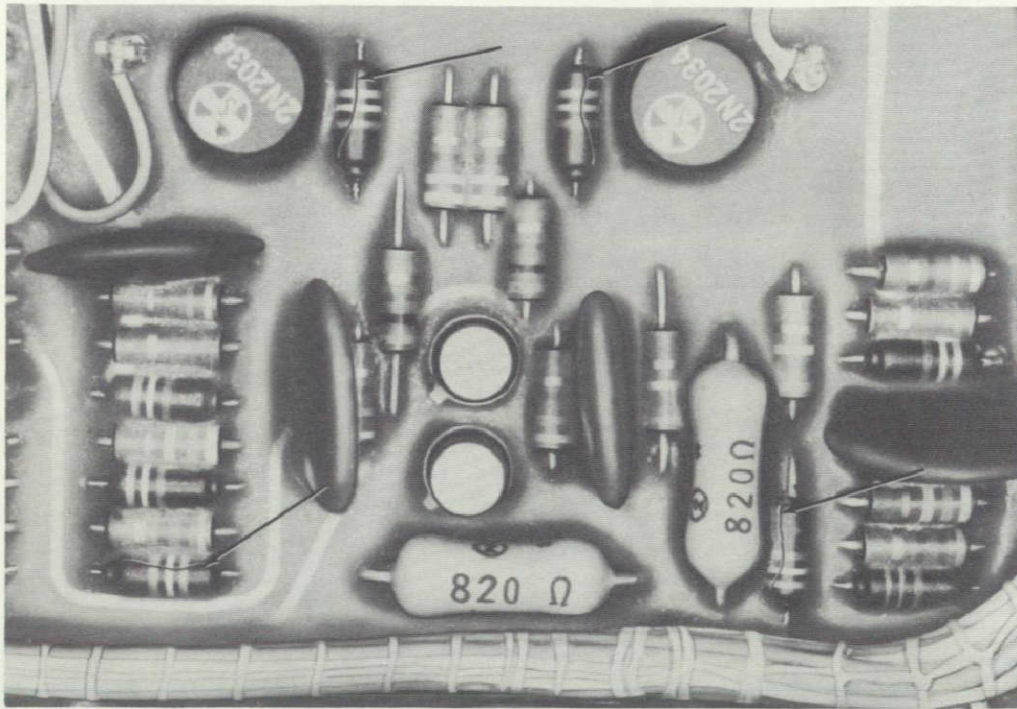


FIGURE 3. CRACKED GLASS COMPONENTS ON PRINTED CIRCUIT BOARDS

8. Cure temperature not to exceed 60° C.
9. Flexibility at low temperature.

With these characteristics in view, various plastics were investigated to determine which would meet these prerequisites for a coating material. The elastomeric polyurethane coating appeared to be the most promising; however, an epoxy lacquer was evaluated along with several polyurethanes which have limited uses.

B. DENNIS 1162 EPOXY INSULATING LACQUER

1. General. Dennis 1162 insulating lacquer is a two-component, modified epoxy coating. The two components are mixed in equal volume to produce a material of spraying viscosity. Pot life of the mixed material is approximately 48 hours. The material, when fully cured (7 days), is clear (amber) in color and will not support combustion.

2. Preparation for Tests.

- a. Molded sample preparation. Dennis 1162 epoxy samples, except those subjected to the thermal shock, coefficient of linear thermal expansion, and component support tests, were molded 0.3 cm thick and 11.4 cm in diameter in an aluminum mold. All samples were cured in a temperature chamber at 23° C and 50 percent relative humidity. During cure time, a relatively large amount of shrinkage occurred.

- b. Printed circuit (PC) board preparation.

- (1) Application specimen. Components were mounted on standard MSFC, etched, gold-plated copper PC boards. The PC boards were constructed in accordance with MSFC-PROC-154, Design and Construction of Printed Circuit Boards. All solder joints were made in accordance with MSFC-PROC-158, Soldering of Electrical Connections (High Reliability).

- (2) Cleaning. The PC boards were cleaned and prepared before mixing the epoxy ingredients. Alcohol, conforming to Specifications MIL-E-463, MIL-A-6091, and MIL-I-0428, was used to remove all solder flux, grease, oil, and other contaminants from the PC boards.

(3) Material. Equal parts of ingredients A and B were placed in a clean glass beaker and thoroughly mixed with a glass rod.

(4) Handling. A copper wire was attached to the corner of the PC board to facilitate handling.

(5) Component support. The epoxy was applied with a soft brush to PC boards containing diodes, capacitors, and resistors too small to be ruggedized. These components ranged in size from 2.5 to 0.6 cm (0.01 to 0.25 watt). The coating was applied in layers to a total thickness of 0.0025 to 0.005 cm. Each layer was allowed one to four hours to dry to a tacky state. The coated PC boards were cured for 168 hours at 23°C and 50 percent relative humidity (the samples were dry enough to handle after 48 hours of cure time). After cure time, the components were easily separated from the PC boards.

3. Test Methods and Results.

a. Hardness. Five 0.6-cm thick samples were produced by laminating 0.3-cm thick molded samples. Following a 40-hour cure time, the hardness of each sample was measured after each 24-hour period for 14 days with a Shore A durometer. The average hardness of the material increased steadily during the test and reached a maximum of 62 (Fig. 4). For detailed test data, see Appendix A, Table I.

b. Moisture absorption. Three molded samples were cured for 120 hours, placed in an oven for 24 hours at 50°C, and then cooled in a desiccator for 24 hours at 23°C. Each sample was weighed and placed on edge in distilled water at 23°C for 24 hours. Then the samples were removed from the water, wiped dry, and reweighed. The samples had an average moisture absorption of 1.12 percent. For detailed test data, see Appendix A, Table II.

c. Surface resistivity. The surface resistivity of three molded samples that had cured for 40 hours was measured with a megohmmeter, using the guarded electrode method. The samples were mounted in a test fixture that held two circular electrodes in place on the surface of the specimen. The average surface resistivity was 2.29×10^8 ohms. For detailed test data, see Appendix A, Table III.

December 16, 1964

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TM X-53181

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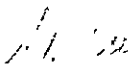
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This document has also been reviewed and approved for technical accuracy.



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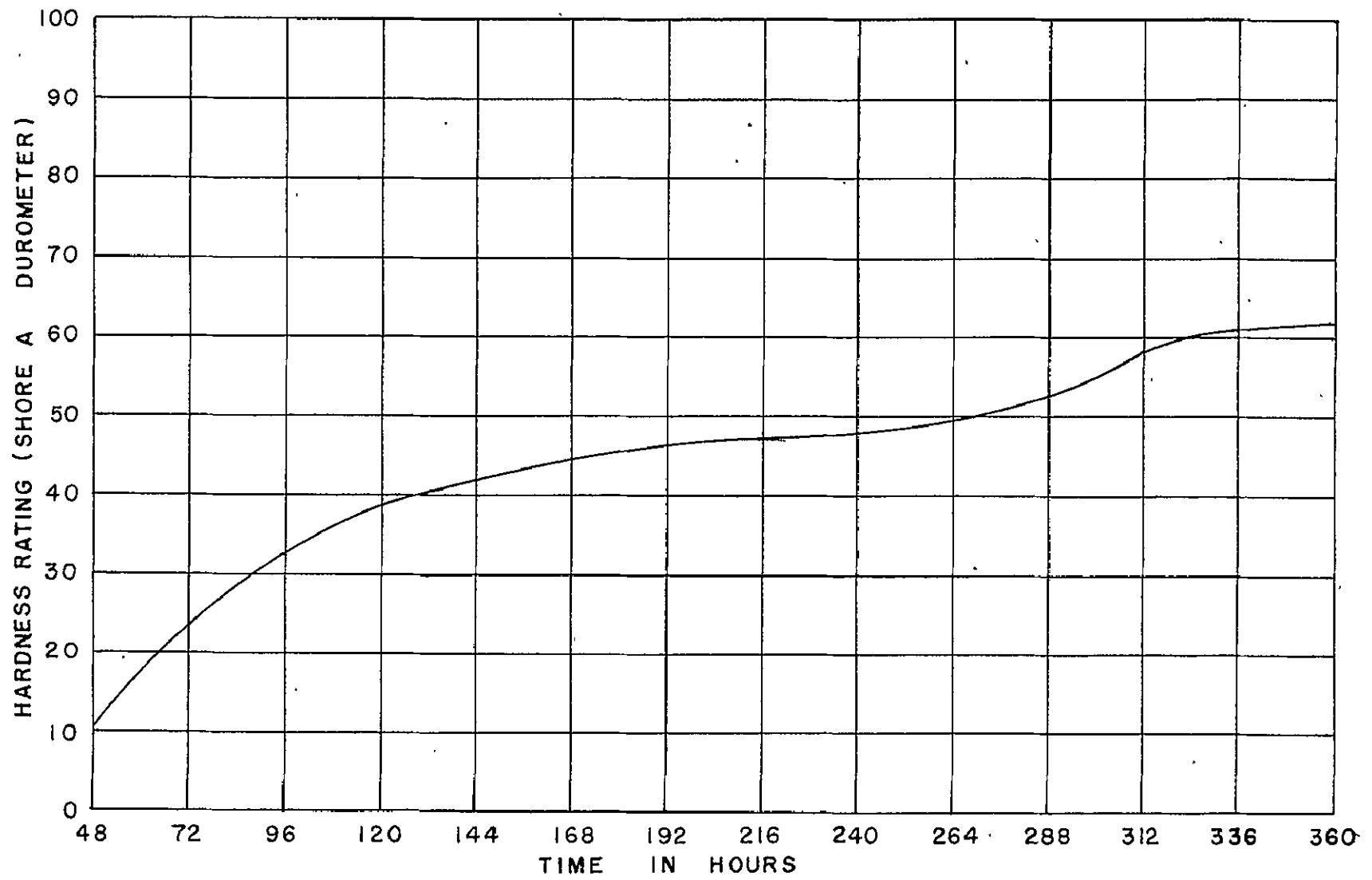


FIGURE 4. DENNIS 1162 EPOXY AVERAGE HARDNESS

d. Dielectric strength. Dielectric strength measurements were made 5 times on each of three samples. Cure time for the samples was 40, 96, and 144 hours; respectively, at 23°C. A spherical electrode was placed on each side of the sample and a 60 Hz potential was applied and increased at a rate of 500 volts per second until breakdown. The sample was immersed in transformer oil to prevent flashover. The average dielectric strength was 7.2×10^4 volts/cm and proved not to be dependent on cure time but on thickness of the sample. For detailed test data, see Appendix A, Table IV.

e. Thermal shock. A 0.01-cm coating of 1162 epoxy was applied to standard MSFC PC boards and allowed to cure for 40 hours at +23°C. More than one coat was needed to obtain the required thickness, and each coat was allowed to dry for 1.5 to 2 hours to a tacky state before applying the next coat. The thermal shock test was performed in accordance with Method 107A, Test Condition B, of MIL-STD-202B. The samples showed no evidence of cracking, peeling, or loosening of the coating from the PC board.

f. Coefficient of linear thermal expansion. Four samples, each approximately 5.1 cm in length and 1.3 cm in diameter, were subjected to temperatures ranging from -30 to +30°C. The coefficient of linear thermal expansion was measured with a glass tube dilatometer. It was anticipated that this material would have a high coefficient of linear thermal expansion; however, the average was 12.52×10^{-5} per degree centigrade. Some trouble was encountered in preparing the samples because the material would cure only in thin films. For detailed test data, see Appendix A, Table V.

C. MAGNA LAMINAR X-500 (POLYURETHANE RESIN)

1. General. Magna Laminar X-500 is a clear polyurethane resin insulating lacquer.

2. Preparation for Tests.

a. Molded sample preparation. Magna Laminar Polyurethane Resin X-500 samples, except those subjected to the thermal shock, coefficient of linear thermal expansion, and component support tests, were molded 0.3 cm thick and 11.4 cm in diameter in an aluminum mold. All samples were cured in a temperature chamber at 23°C and 50 percent relative humidity. During cure time, a large amount of shrinkage occurred.

b. PC board preparation.

(1) Application specimen. Components were mounted on standard MSFC etched, gold-plated copper PC boards. The PC boards were constructed in accordance with MSFC-PROC-154, Design and Construction of Printed Circuit Boards. All solder joints were made in accordance with MSFC-PROC-158, Soldering of Electrical Connections (High Reliability).

(2) Cleaning. The PC boards were cleaned and prepared prior to mixing the polyurethane ingredients. Alcohol, conforming to Specifications MIL-E-463, MIL-A-6091, and MIL-I-0428, was used to remove all solder flux, grease, oil, and other contaminants from the PC boards.

(3) Material. The polyurethane resin and hardener (three parts resin and one part hardener by volume) were placed in a clean glass beaker. The contents of the beaker were then thoroughly mixed, using a glass rod.

(4) Handling. A copper wire was attached to the corner of the PC board to facilitate handling.

(5) Component support. Polyurethane resin X-500 was applied with a soft brush to a PC board containing diodes, capacitors, and resistors too small to be ruggedized. These components ranged in size from 2.5 to 0.6 cm (0.01 to 0.25 watt). The coating was built up to a thickness of 0.005 to 0.008 cm. Each layer was allowed 2 to 2.5 hours to dry to a tacky state. The coated PC boards were cured for 168 hours at 23°C and 50 percent relative humidity. After cure time, the components easily broke away from the PC boards.

3. Test Methods and Results.

a. Hardness. Five 0.6-cm thick samples were produced by laminating 0.3-cm thick molded samples. Following a 40-hour cure time, the hardness of each sample was measured after each 24-hour period for 14 days with a Shore A durometer. The average hardness of the material increased steadily during the test and reached a maximum of 95 (Fig. 5). For detailed test data, see Appendix A, Table VI.

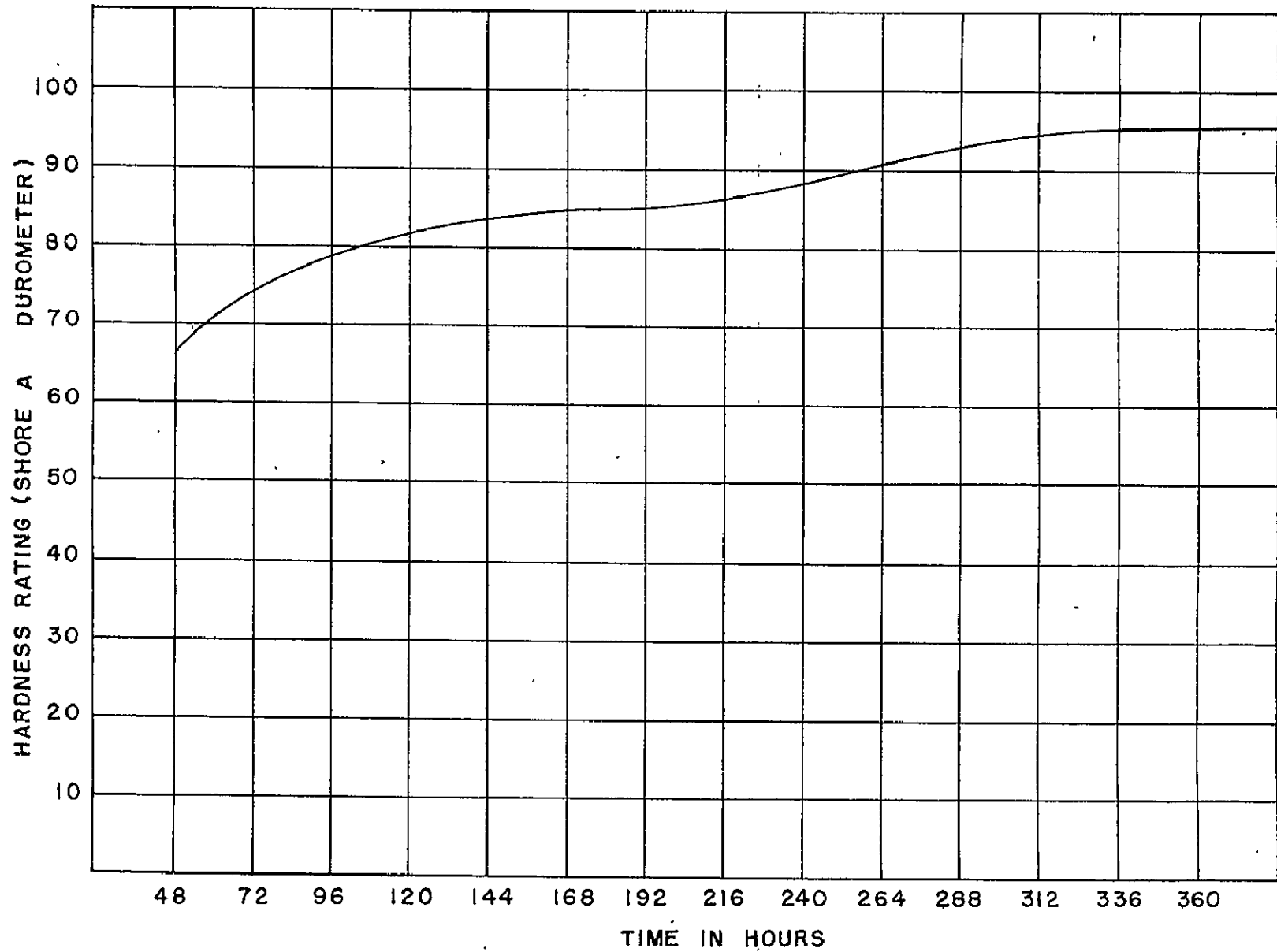


FIGURE 5. MAGNA LAMINAR X-500 AVERAGE HARDNESS

b. Moisture absorption. Four molded samples were cured for 120 hours, placed in an oven for 24 hours at 50°C, and then cooled in a dessicator for 24 hours at 23°C. Each sample was then weighed and placed on edge in distilled water at 23°C for 24 hours. The samples were then removed from the water, wiped dry, and reweighed. The samples had an average moisture absorption of 1.53 percent. For detailed test data, see Appendix A, Table VII.

c. Surface resistivity. The surface resistivity of five molded samples, which had cured for 40 hours, was measured with a megohmmeter, using the guarded electrode method. The samples were mounted in a test fixture which held two circular electrodes in place on the surface of the specimens. The average surface resistivity was 9.32×10^{11} ohms. For detailed test data, see Appendix A, Table VIII.

d. Dielectric strength. Dielectric strength measurements were made five times on each of three samples. Cure time for the samples was 40, 96, and 144 hours, respectively, at 23°C. A spherical electrode was placed on each side of a sample, and a 60 Hz potential was applied and increased at a rate of 500 volts per second until breakdown. The sample was immersed in transformer oil to prevent flashover. The average dielectric strength was 3.32×10^5 volts/cm and proved not to be dependent on cure time but on thickness of the sample. For detailed test data, see Appendix A, Table IX.

e. Thermal shock. A 0.01-cm coating of X-500 was applied to standard MSFC PC boards and allowed to cure for 40 hours at 23°C. More than one coat of the material was needed to obtain the required thickness, and each coat was allowed to dry for 1.5 to 2 hours to a tacky state before applying the next coat. The thermal shock test was performed in accordance with Method 107A, Test Condition B of MIL-STD-202B. The samples showed no evidence of cracking, peeling, or loosening of the coating from the PC board.

f. Coefficient of linear thermal expansion. Six samples, each approximately 5.1 cm in length and 1.3 cm in diameter, were subjected to temperatures ranging from -30 to +30°C. The coefficient of linear thermal expansion was measured with a glass tube dilatometer. It was anticipated that this material would have a high coefficient of linear thermal expansion; however, the average was 13.55×10^{-5} per degree centigrade. Some trouble was encountered in preparing the samples because the material would cure only in thin films. For detailed test data, see Appendix A, Table X.

D. PERMACEL ER-6016 POLYURETHANE COATING

1. General. Permacel ER-6016 polyurethane coating is cured by solvent evaporation and subsequent reaction of the polyurethane with the moisture in the air.

2. Preparation for Tests.

a. Molded sample preparation. Permacel ER-6016 polyurethane samples, except those subjected to the moisture absorption, moisture vapor transmission, and component support tests, were molded 0.004 to 0.008 cm thick. A silicon spray releasing agent was used for mold release. Samples cured at room conditions were transparent.

b. PC board preparation.

(1) Application specimen. A standard MSFC etched, gold-plated copper PC board was used to mount components as specified in MSFC-PROC-154, Design and Construction of Printed Circuit Boards. All solder joints were made in accordance with MSFC-PROC-158, Soldering of Electrical Connections (High Reliability).

(2) Cleaning. The samples were cleaned and dried before the Permacel ingredients were prepared. Alcohol, conforming to Specifications MIL-E-463, MIL-A-6091, and MIL-I-0428, was used to remove all solder flux, grease, oil, and other contaminants. All samples were then thoroughly dried before preparing coating material.

(3) Material. Permacel ER-6016 is a premixed material that can be applied to electrical parts and components by a brushing, dipping, or spraying process.

(4) Handling. A copper wire was attached to the corner of the PC board to facilitate handling.

(5) Component support. Permacel ER-6016 was applied with a soft brush to PC boards containing diodes, capacitors, and resistors too small to be ruggedized. These components ranged in size from 2.5 to 0.6 cm (0.10 to 1.25 watt). The coating was applied in layers to a total thickness of 0.005 to 0.008 cm. Each layer was allowed 1 to 4 hours to dry to a tacky state. The coated PC boards were cured for 168 hours at 23°C and 50 percent relative humidity. After cure time, the components easily broke away from the PC boards. (The samples were dry enough to handle after 48 hours of cure time.)

3. Test Methods and Results.

a. Dielectric strength. The dielectric strength was measured on three samples. The cure times of the samples were 168 hours at 21°C, 336 hours at 150°C, and 24 hours at 200°C, respectively. All samples were allowed to cool to room temperature before testing. Polished steel electrodes were placed on opposite sides of the sample and 60 Hz voltage was applied at a rate of 500 volts per second until breakdown occurred. The average dielectric strength was 1.55×10^6 volts/cm (see Appendix A, Table XI).

b. Volume resistivity. A test potential of 500 volts was applied to three samples, and the volume resistivity was measured with the aid of a holding fixture employing the voltmeter-ohmmeter-guarded electrode method. The average volume resistivity was 3.15×10^{13} ohm/cm (see Appendix A, Table XII).

c. Insulation resistance. The insulation resistance of three samples was measured by spraying each sample to a thickness of 0.008 cm on a Teflon mold having a centrally embedded electrode. The samples had cure times of 2, 3, and 24 hours at 23°C. A test potential of 500 volts was applied to each cured sample through a probe placed on the far side of the mold electrode. Measurements were made and electrification was concluded within 2 minutes. The average insulation resistance was 6.1×10^{11} ohms (see Appendix A, Table XIII).

d. Dielectric constant and dissipation factor. Three samples sprayed to a thickness of 0.008 cm and a diameter of 10.8 cm were cured for one week at 23°C. Each sample was tested at 1 kHz and 100 kHz. The average dielectric constant was 3.74 at 1 kHz and 3.97 at 100 kHz. The average dissipation factor was 0.022 at 1 kHz and 0.042 at 100 kHz (see Appendix A, Tables XIV and XV).

e. Moisture absorption. Four molded samples, 10.8 cm in diameter and 0.3 cm thick, were cured for 168 hours at 23°C and 50 percent relative humidity and then cooled in a dessicator for 24 hours at 23°C. The samples were weighed and placed on edge in distilled water at 23°C for 24 hours. The samples were then removed from the water, wiped dry, and reweighed. The samples had an average moisture absorption of 0.91 percent weight gain (see Appendix A, Table XVI).

f. Moisture vapor transmission. Moisture vapor transmission was measured on four samples 10.8 cm in diameter. One sample was poured to a thickness of 0.005 cm, and the other three were poured to a thickness of 0.25 cm.

The 0.005-cm sample was cured for one week at 23°C. The 0.25-cm samples were poured in successive thin layers (allowing time for each layer to dry to a tacky state) until the 0.25-cm thickness was obtained. The 0.25-cm samples were then cured in two steps: one week at 23°C, followed by oven-drying at 50°C for 24 hours. Each sample was then placed on a dish filled with distilled water to a level within 25 mm of the underside of the sample. The sample was sealed to the dish, and the entire setup was immediately weighed. Each setup was then placed in an upright position in a temperature chamber at 23°C and 50 percent relative humidity with continuous air circulation over the exposed sample surfaces. Successive weighings were made at one-hour intervals until constant rates of gain were obtained. A higher rate of moisture vapor transmission was experienced in the 0.005-cm specimen than in the 0.25-cm specimens. However, this rate was not linear with respect to thickness; i. e., the 0.005-cm specimen's transmission rate was not 50 times that of the 0.25-cm specimens. The average rate of moisture vapor transmission in the 0.25-cm specimens was .0662 g/cm² (see Appendix A, Table XVII).

g. Viscosity. A Brookfield viscosimeter, with number 7 spindle operating at 10 revolutions per minute, was used to measure the viscosity of the Permacel. The Permacel and the viscosimeter were maintained at a uniform temperature of 25 (±2)°C. Measurements were taken when the pointer of the viscosimeter assumed a steady position. The average viscosity was 270 centipoise.

h. Hardness. The hardness of the Permacel was measured with a Shore A durometer (A scale) following a 168-hour cure period. The average hardness was 65.

i. Tensile strength. The Permacel specimen was placed in the grips of the testing machine and was adjusted symmetrically so that the tension was distributed uniformly over the cross section of the specimen. The grips traveled at a constant speed of 50 (± 2.5) cm per minute until the specimen ruptured. The average tensile strength was 2.84×10^7 N/m² (4120 psi).

j. Elongation. The Permacel specimen was placed in the grips of the testing machine. Two parallel benchmarks were placed on the specimen and the specimen was adjusted symmetrically so that the tension was distributed uniformly over the specimen cross section. The grips traveled at a constant speed of 50 (± 2.5) cm per minute until the specimen ruptured. The average elongation was 110 percent and the modulus of elongation was 2.6×10^7 N/m². (3760 psi).

E. PRODUCTS RESEARCH PR-1538 POLYURETHANE COATING

1. General. PR-1538 is a low viscosity, chemically curing polyurethane compound that is supplied in two-part units or in premixed form frozen in cartridges. PR-1538 cures at room temperature; however, cure may be accelerated by the application of heat.

2. Preparation for Tests.

a. Molded sample preparation. PR-1538 samples of required sizes for testing were molded in an aluminum mold and cured for 14 hours at 55°C.

b. PC board preparation.

(1) Application specimens. Components were mounted on standard MSFC etched, gold-plated copper PC boards. The PC boards were constructed in accordance with MSFC-PROC-154, Design and Construction of Printed Circuit Boards. All solder joints were made in accordance with MSFC-PROC-158, Soldering of Electrical Connections (High Reliability).

(2) Cleaning. The PC boards were cleaned and prepared prior to mixing the polyurethane ingredients. Alcohol, conforming to Specifications MIL-E-463, MIL-A-6091, and MIL-I-0428, was used to remove all solder flux, grease, oil, and other contaminants from the PC boards.

(3) Handling. A copper wire was attached to the corner of the PC board to facilitate handling.

(4) Material. The materials (parts A and B) were placed in a clean glass beaker and mixed thoroughly with a glass rod.

3. Test Methods and Results.

a. Low-temperature flexibility. The hardness of three 2.5-cm cubes of PR-1538 was measured at 25°C with a Shore A durometer. The specimens were then placed in a cold box and allowed to stabilize at -50°C; then the hardness was measured again. The average hardness value for the three samples at 25°C was Shore A 80. At -50°C, the average hardness value was Shore A 85, indicating that polyurethane has excellent low-temperature flexibility.

b. Electrical and Physical Properties. Electrical and physical properties of PR-1538 were tested in accordance with American Society for Testing Materials (Plastics edition), FED-STD-406 and MIL-I-16923D. For test results, see Appendix A, Table XVIII.

c. Adhesion to G-10 substrate. Five test sets of epoxy-fiberglass panels (G-10) were cleaned thoroughly in xylene and bonded, unprimed, using a minimum glue line. The samples were cured for 14 hours at 55°C and then were pulled on an Instron tensile tester at a crosshead speed of 0.5 cm per minute. The maximum adhesion of the samples was 382.46 N/cm² (555 psi), the minimum adhesion of the samples was 264.78 N/cm² (393 psi), and the average adhesion of the samples was 313.81 N/cm² (460 psi).

d. Thermal shock. Ten PC boards (7.6 by 10.8 by 2.9 cm) containing an average of 24 diodes (Hughes 1N626) per board and arranged in various patterns and lead lengths were coated with polyurethane PR-1538 and cured 14 hours at 55°C. The PC boards were examined for broken diodes and then subjected to 10 temperature cycles on the following schedule: 1.0 hour at -50°C, 0.5 hour at +25°C, 1.0 hour at +85°C, and 0.5 hour at +25°C. The PC boards were then examined with a 15-power microscope for fractured diodes. Microscopic examination of the 240 diodes indicated no fractures in the conformal coating, the paint, or the glass body.

e. Compatibility. Polyurethane PR-1538 was cured for 14 hours at 55°C in contact with the following samples to determine compatibility with various PC board materials and components:

- (1) Silicone release agent: Dow Corning No. 7
- (2) Vinyl tubing: MIL-I-631
- (3) Vinyl tubing: MIL-I-7444B
- (4) Silastic RTV rubber: Dow Corning 881
- (5) Epoxy: Hysol 12-007
- (6) Epoxy: Armstrong X81
- (7) Mold release: Ram 225
- (8) Masking tape: Scotch Brand 471
- (9) Masking tape: Scotch Brand 56

At the end of the cure time, the polyurethane was examined for tackiness, soft spots, and any discoloration that would indicate incompatibility and incomplete cure. Evidence of incompatibility was found in samples of polyurethane cured in contact with silicone release agent, Silastic RTV rubber, and vinyl tubing (MIL-I-7444B). There was no indication of incompatibility with any of the epoxy test samples when the epoxy materials were completely cured before application of the polyurethane PR-1538. PC board materials, vinyl tubing (MIL-I-631), components, and masking materials displayed excellent compatibility.

f. Filletting. Three PC boards were coated with PR-1538. Each board contained 4 components with diameters of 0.16, 0.32, 0.64, and 0.95 cm, respectively. The PC boards were cured in the following manner:

(1) Board "A" was allowed to stabilize at room temperature for 4 hours at less than 40 percent relative humidity and then cured for 14 hours at 55°C.

(2) Board "B" was cured for 14 hours at 55°C.

(3) Board "C" was cured for 14 hours at 88°C.

The components were then examined to see what effect precure and cure temperatures would have on fillets. No effect was visible on the size and form of the fillet by eliminating the precure or raising the cure temperature.

SECTION IV. CONCLUSIONS

A. CORDWOOD MODULE POTTING COMPOUNDS

The filled epoxies, Stycast 1090 and Stycast 2651, cured with Catalyst 11, did not cause fracture of solder joints or radically affect component values. The electrical and physical properties, application characteristics, and low coefficient of expansion of these compounds are sufficient to warrant using them for potting cordwood-type modules. IBM LDT-7A may be used, provided the module length does not exceed 1.3 cm.

Investigation of these and other materials will be continued so that maximum reliability for flight components can be assured and additional sources of material may be qualified.

B. UNFAVORABLE CONFORMAL COATINGS

Dennis 1162 epoxy, Magna Laminar X-500, and Permacel ER-6016, as tested, are not considered satisfactory for use as conformal coatings. These materials had the following disadvantages:

1. It was necessary to use more than one brushed layer of material to obtain a thickness in excess of 0.0025 cm. Each layer required 1 to 4 hours to dry to a tacky state before application of the next layer.
2. One brushed layer of material did not provide sufficient support to components too small to be ruggedized that were mounted on PC boards.

Single applications and thick sections of Permacel ER-6016 were difficult to pour and cure without the formation of air bubbles in the cured material. Samples of ER-6016 that were cured at elevated temperatures were yellow and difficult to release from the mold.

These materials in a higher viscosity would be eligible for reevaluation, and in certain cases the material may be used where a very thin coat is desired and no component support is needed.

C. FAVORABLE CONFORMAL COATINGS

Hysol 12-005 and Hysol 12-007 do not fracture glass components when they have been sleeved with vinyl. Products Research 1538 does not contribute to the fracture of critical glass components. The electrical and physical properties, application characteristics, and flexibility of PR-1538 warrant its use as a conformal coating where critical glass components are used. The investigation of this material and others will be continued to assure maximum reliability of flight components and to qualify additional sources of material.

APPENDIX A
TEST DATA SHEETS

Table I. Dennis 1162 Epoxy Hardness.

HARDNESS Shore A

Sample	Cure Time (hours)													
	48	72	96	120	144	168	192	216	240	264	288	312	336	360
1	11	22	32	38	39	44	47	46	46	49	56	59	62	62
2	10	25	33	38	42	46	45	47	49	52	57	59	61	62
3	10	23	33	39	43	44	46	48	48	53	57	58	60	60
4	10	23	33	38	43	45	48	46	49	51	56	58	60	62
5	11	23	33	39	43	46	45	47	48	50	56	59	59	63
Average	10	23	33	38	42	45	46	47	48	53	56	59	60	62

Table II. Dennis 1162 Epoxy Moisture Absorption.

Sample	Weight Before Test (grams)	Weight After Test (grams)	Moisture Absorption (%)
1	10.1664	10.2841	1.15
2	10.5537	10.6711	1.11
3	11.0843	11.2054	1.09
Average	10.6015	10.7202	1.12

Table III. Dennis 1162 Epoxy Surface Resistivity.

Sample	Surface Resistivity (ohms)
1	1.93×10^8
2	2.12×10^8
3	2.83×10^8
Average	2.29×10^8

Table IV. . Dennis 1162 Epoxy Dielectric Strength.

Sample 1

Reading	Thick-ness (cm)	Break-down Voltage (Volts)	Volts per cm
1	0.13	5800	44,700
2	0.12	5600	45,800
3	0.13	5700	42,300
4	0.13	5700	42,300
5	0.13	5600	43,100
Average	0.13	5700	43,700

Sample 2

Reading	Thick-ness (cm)	Break-down Voltage (Volts)	Volts per cm
1	0.063	7300	115,000
2	0.063	6500	102,000
3	0.061	7200	118,000
4	0.058	7300	125,000
5	0.058	6900	118,000
Average	0.061	7040	116,000

Sample 3

Reading	Thickness (cm)	Breakdown Voltage (Volts)	Volts per cm
1	0.10	5600	55,100
2	0.10	5800	57,000
3	0.09	5700	57,500
4	0.10	5600	54,700
5	0.10	5900	58,000
Average	0.10	5720	56,300

NOTE: Sample 1 was cured for 40 hours at +23°C.
 Sample 2 was cured for 96 hours at +23°C.
 Sample 3 was cured for 144 hours at +23°C.

Table V. Dennis 1162 Epoxy Coefficient of Thermal Expansion.

Sample	Temperature (C ^o)	Change in Length (cm)	Coefficient of Thermal Expansion
1	+30 to -30	0.0328	10.55×10^{-5}
2	-30 to +30	0.0455	14.77×10^{-5}
3	+30 to -30	0.0373	12.13×10^{-5}
4	-30 to +30	0.0388	12.62×10^{-5}
Average		0.0386	12.52×10^{-5}

NOTE: Sample length = 5.1 cm.

Table VI. Magna Laminar X-500 Hardness.

		HARDNESS Shore A													
Sample	Cure Time (hours)														
	48	72	96	120	144	168	192	216	240	264	288	312	336	360	
1	65	74	80	80	82	86	85	89	90	92	94	93	96	97	
2	62	78	75	79	82	87	85	86	86	86	96	94	92	97	
3	68	74	78	82	83	84	84	90	90	91	93	96	94	93	
4	64	75	78	83	84	85	86	86	86	92	95	95	96	97	
5	68	77	80	82	87	84	87	86	88	92	95	95	97	92	
Average	65	76	78	81	84	85	85	87	88	93	95	95	95	95	

Table VII. Magna Laminar X-500 Moisture Absorption.

Sample	Weight Before Test (grams)	Weight After Test (grams)	Moisture Absorption (%)
1	6.8092	6.9652	2.35
2	6.7262	6.8206	1.40
3	6.3040	6.3783	1.17
4	6.2162	6.2916	1.21
Average	6.5139	6.6139	1.53

Table VIII Magna Laminar X-500 Surface Resistivity.

Sample	Surface Resistivity (ohms)
1	15.07×10^{11}
2	9.42×10^{11}
3	8.00×10^{11}
4	8.94×10^{11}
5	5.18×10^{11}
Average	9.32×10^{11}

Table IX. Magna Laminar X-500 Dielectric Strength.

Sample 1
(Cured 40 hours at 23°C)

Reading	Thick- ness (cm)	Break- down Voltage (kV)	Volts per cm
1	0.074	26.0	352,000
2	0.072	23.6	326,000
3	0.074	24.2	329,000
4	0.074	26.0	354,000
5	0.069	26.2	389,000
Average	0.072	25.2	342,000

Sample 2
(Cured 96 hours at 23°C)

Reading	Thick- ness (cm)	Break- down Voltage (kV)	Volts per cm
1	0.060	21.9	362,000
2	0.068	24.2	361,000
3	0.069	22.2	322,000
4	0.066	24.8	379,000
5	0.066	26.3	389,000
Average	0.066	23.9	371,000

Sample 3
(Cured 144 hours at 23°C)

Reading	Thick- ness (cm)	Break- down Voltage (kV)	Volts per cm
1	0.08	22	279,000
2	0.08	24	305,000
3	0.07	19.5	265,000
4	0.08	23.5	289,000
5	0.08	22	279,000
Average	0.08	22	284,000

Table X. Magna Laminar X-500 Coefficient
of Linear Thermal Expansion.

Sample	Temperature (° C)	Change in Length (cm)	Coefficient of Linear Thermal Expansion
1	+30 to -30	0.0376	13.57×10^{-5}
2	-30 to +30	0.0371	13.39×10^{-5}
3	+30 to -30	0.0376	13.57×10^{-5}
4	-30 to +30	0.0381	13.75×10^{-5}
5	+30 to -30	0.0376	13.57×10^{-5}
6	-30 to +30	0.0373	13.49×10^{-5}
Average		0.0376	13.55×10^{-5}

NOTE: Sample length = 4.6 cm

Table XI. Permacel ER-6016 Dielectric Strength.

Sample	Breakdown Voltage	Volts per cm
24 hr at 200° C	5500V	1,440,000
168 hr at 21° C	6000V	1,570,000
336 hr at 150° C	6200V	1,630,000

Table XII. Permacel ER-6016 Volume Resistivity.

Sample	R $\Omega \times 10^9$	Ω -cm $\Omega \times 10^{13}$
1	5.0	4.49
2	2.5	2.25
3	3.0	2.70
Average	3.5	3.15

Table XIII. Permacel ER-6016 Insulation Resistance.

Sample	Insulation Resistance
2 hr at 23° C	$0.28\Omega \times 10^{12}$
5 hr at 23° C	$0.63\Omega \times 10^{12}$
24 hr at 23° C	$0.91\Omega \times 10^{12}$

Table XIV. Permacel ER-6016 Dielectric Constant.

Sample	Dielectric Constant 1 kHz	Dielectric Constant 100 kHz
1	3.69	3.99
2	3.64	3.76
3	3.89	4.14
Average	3.74	3.97

Table XV. Permacel ER-6016 Dissipation Factor.

Sample	Dissipation Factor at 1 kHz	Dissipation Factor at 100 kHz
1	0.016	0.056
2	0.006	0.010
3	0.045	0.060
Average	0.022	0.042

Table XVI. Permacel ER-6016 Moisture Absorption.

Sample	Weight Before Test (grams)	Weight After Test (grams)	Moisture Absorption (%)
1	27.53	27.79	0.94
2	30.05	30.29	0.80
3	29.30	29.59	0.99
Average	28.96	29.22	0.91

Table XVII. Permacel ER-6016 Moisture Vapor Transmission (mvt)

Sample	Weight Before Test (grams)	Weight After Test (grams)	Mvt gram/cm ²
1	288.05	227.43	0.152
2	335.41	235.27	0.0414
3	236.54	236.38	0.0474
4	254.46	254.38	0.0237
Average	263.65	238.36	0.0662

Table XVIII. Products Research PR-1538 Electrical and Physical Properties.

Measurement	Value
Electrical Properties:	
Dielectric constant (1 MHz)	3.99
Dissipation factor (1 MHz)	0.017
Dielectric strength	212,000 volts/cm
Volume resistivity (+25°C)	2.78×10^{13} ohms/cm
Volume resistivity (+128°C)	2.68×10^{10} ohms/cm
Surface resistivity	0.81×10^{13} ohms
Arc resistance	126 seconds
Insulation resistance (+25°C)	Infinity
Insulation resistance (+128°C)	1.85×10^9 ohms
Volume resistivity after moisture (submerged in water for 21 days)	1×10^9 ohms/cm
Physical Properties:	
Tensile strength	2059.40 N/cm ² (3000 psi)
Elongation	52.50%
Shrinkage	1.90%
Compression set	15.0%
Tear strength	215.75 N/cm ² (315 psi)