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THIN CONFORMAL COATINGS
A BOON TO THE ELECTRONIC ENGINEER

by

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ABSTRACT

Thin-film conformal coatings are truly the ounce or prevention that is worth many pounds of cure. Light, thin, and taking only a second to apply - slightly longer to cure - they help to maintain the electronic curcuitry in a condition very close to its sterile design environment.

Since many electronic units must operate in differing environments and at various altitudes, and since their size is constantly decreasing ~~and their size is constantly decreasing~~ and their importance increasing, it is important that the electronic engineer provide maximum environmental and mechanical protection at the lowest cost and with the least weight and change in electronic characteristics.

For approximately three years, NASA/s Kennedy Space Center has been using a family of thin polyester-type polyurethane coatings which give excellant protection with very little change in electrical characteristics at a much lower cost than previous thicker coatings.

This paper discusses the various types of coatings and the advantages of the thin-film coatings in operation, time, and cost.

1. INTRODUCTION

There is an increasing interest by electronic engineers not only in designing better and more reliable printed circuit boards, but in packaging these delicate circuits so that they will operate accurately every time and under all environmental conditions. For several years conformal coatings were more of a plague than a help to electronic designers. NASA as well as other organizations and companies required a heavy conformal coating that changed the electrical characteristics of printed circuits as well as adding to the manufacturing headaches and costs. On the other hand, many groups tried using thin spray-on varnishes to prevent environmental attack and provide the necessary protection.

Neither course was quite adequate. Development of the thin-film conformal coatings did provide the desired protection at little or no change in characteristics - truly a boon to the electronic engineer.

2. DEFINITION AND PURPOSE

Conformal coatings may be any of a large variety of substances which cover and conform to the outline or any surface or structure. The name usually applies to coatings on electrical or electronic printed circuit boards or packages. As applied to printed circuitry, they usually serve four purposes: environmental protection, handling, ruggedization, and insulation.

By environmental protection we mean protection from moisture and other air-born contaminants, especially salts and sulphur compounds. It also may include prevention of fungus growth.

Handling protection is afforded to prevent damage from the "hand-born" contaminants such as salts, oils, and sulphur compounds which are deposited on components during the final assembly stages of manufacturing or during later testing in the field.

Ruggedization due to shock or vibration applies to protection both during in-plant handling and testing, and in use.

Its fourth purpose is insulation protection. As insulation, it is superior to the normal insulation afforded by the air space between components or conducting surfaces as well as preventing shorting by moisture or other air-born or "hand-born" contaminants. Simply stated, the purpose of conformal coating is to maintain the electronic circuitry in a condition very close to its sterile design environment.

One writer has stated, "The design of the printed circuit assembly, including the component mounting, must be compatible with the conformal coating material." The opposite is true. The electronic design is the critical element. Conformal coatings should be selected or designed and formulated to be both compatible with the design and function, and not appreciably change the electrical characteristics of the circuit to which it is applied.

3. TYPES OF COATINGS

There are several categories of coatings used on printed circuit boards: jelly-type, foam-type, rigid, elastomeric, and aerosol-type varnishes. These types may be further broken down and other combinations exist.

Jelly-type coatings are usually silicone jelly or gels applied as salves. Some form a semi-hard exterior yet stay soft internally, some never harden, and some become semi-hard or gel throughout. These may be colored (filled), opaque, or transparent. They are almost always flexible to some extent and are usually very easy to repair through. This coating is usually relatively thick and may often be classed as potting.

Foam-type coatings, like the jelly-type are thick and more potting than coating. Their purpose is usually light weight encapsulation.

Most rigid coatings are of epoxy or modified epoxy resins. Mr. A. Z. Orlowski has demonstrated the value of thin film epoxies for coatings in studies performed for the U. S. Army Electronics Command.[1] Use of other than thin-film epoxies for conformal coatings has largely been discontinued because the differential in coefficients of thermal expansion between the board, components, and coating often cracks components or solder joints.

Many conformal coatings used on printed circuit boards are elastomeric - they stretch. Some, like most polyurethanes, are expected to stretch twice their normal dimension and return to their normal shape without losing their physical characteristics. A wide variety of materials which fall into the general elastomeric category and are used for this purpose are: modified epoxies, polyurethanes, silicones, and RTV silicone rubbers.

The last category of coatings, aerosol-type, are so named because they are packaged in aerosol spray cans for convenience. A variety of materials are included: epoxies or modified epoxies, phenolics, polyurethanes, acrylics.

These coatings are generally one part, Freon blown, solvent curing types

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(1) "Conformal Coatings for Printed Circuit Assemblies," Department of Army Project No. 5999-0004 (July 1, 1961 - June 30, 1963); and "Conformal Coatings for Printed Circuit Assemblies," Department of Army Project No. 5999-A005 (July 15, 1964 - January 15, 1965).

which usually give extremely thin coatings. They are very easy to store, and easy to use, but do not usually provide sufficient protection for printed circuit applications. Developments in this field are showing promise and at least one coating, recently released, appears to have most of the desired characteristics.

4. DESIRED CHARACTERISTICS OF COATINGS

We have discussed the generally available coating categories but to the progressive materials formulator it is a question of "What characteristics do the design engineers need in a coating?"

This was the question which faced four of us when we met at NASA's Marshall Space Flight Center (MSFC) several years ago. Two of the engineers had worked in the development of potting compounds for cable encapsulation and had applied these same thick materials to printed circuit boards. It was this same group who set up and taught the first school of potting, molding and conformal coating for NASA at MSFC. Two of us were from NASA's Kennedy Space Center.

We had found that the thick polyether-type, 100% solids polyurethanes, had very distinct drawbacks for the designer, manufacturer, and user. There were mixing problems: one part crystallized and had to be melted and cooled before mixing, the mix had to be vacuumed to remove entrapped air, and the vacuum equipment was prohibitive because of cost to many small contractors. Pot life was short - only 45 minutes to one hour. Cure time was long and usually required extensive oven space for large production. Masking and demasking required meticulous care to prevent damage to the coating, and left the cut board edges open for moisture penetration. Removal of the coating for replacement of components was difficult. In-use cycling of the boards caused the coating to age quickly. This caused intermittant and difficult-to-detect problems due to cracks in components and solder joints. This was probably due to isocyanate dissipation from the loosely linked polyether-type polyurethane. We therefore decided that a new type material was needed to satisfy our needs as well as the needs of the designer and manufacturer.

Ideally the designer would desire that the circuit and board be built and used as designed. By so doing, the native characteristics of the various parts and components could be utilized to their optimum. Naturally, this ideal condition is not practical or possible. Practically, the designer needs to maintain his circuit in as close to the sterile design environment as possible. He desires that the electrical and mechanical characteristics of the board not be changed or be changed as little as possible.

he desires protection of his parts and components from handling, the environment, and the possible shock and vibration of use This requires a coating which will seal the board from moisture as much as possible - especially along the cut edges - and will coat and seal all those components which can be coated. (Parts such as piston-type capacitors cannot be coated entirely but must be masked to prevent the coating from freezing their adjustments. Tuneable potentiometers can be coated since the thin coating is easily broken if any further adjustment is required.)

This coating must not appreciably affect the electrical characteristics of the circuit or individual parts and must be strong and elastic enough to withstand the abrasion, shock, and vibration of handling, testing, and shipping. Such coatings also must not support fungi.

Naturally both the designer and manufacturer - in order to compete in the market - must have a design that is competitive in parts and manufacturing. This then requires an inexpensive coating which can be secured from a veriety of reasonable sources; will have a reasonably long shelf-life; is easy to mix and apply by brush, dip or normal spray equipment; requires very little or no masking and unmasking; has a long pot life (or use time); a short cure time with the minimum of capital equipment; is safe to handle; is easy to inspect; is easy to repair through; and causes no change in the design characteristics of the board which will require extensive adjustment or many rejections after coating. The coating must be rugged enough to maintain the integrity of the coating and protect the unit during further phases of testing and assembly.

The needs of the user are to purchase from a number of manufacturers, at competitive prices, a circuit or system which will operate through the range of its design parameters with the least problems and downtime and with the easiest maintenance possible for the longest period of time. This requires a coating which will protect the circuit under variable temperature and moisture conditions, which allows easy inspection and repair, and can be reapplied easily for continued protection. It must not support fungi or shrink during thermal cycling or ageing. It must not melt and run during normal operation. It must be flame retardant but if ignited, it must not drip and propagate the fire.

Since the above needs put various restraints on a coating, it seems desirable that we consider what characteristics are peculiar to each and common to all three groups. Since most of these characteristics are relative, I will discuss them in relation to the coatings that have previously been used.

4.1 MECHANICAL CHARACTERISTICS

The prime purpose of the coating is sealing and low moisture absorption. Wear resistance is next in importance. Polyurethanes rank highest here with epoxies next.

Normal application thickness must be closely controlled since it directly effects the electrical properties. Mr. Orlowski[1] found that thicknesses of 2 mils (0.002 inches) and less do not appreciable change the Q-factor. At thicknesses over 2 mils the change in Q increases very rapidly and makes major retuning or redesign necessary. Our tests[2] and extensive experience at Cape Kennedy and Kennedy Space Center bear this out.

Shrinkage, as has been mentioned earlier, is definitely important since it can cause stress buildup and cracks in parts or connections on the board. Shrinkage sometimes is due to material ageing or breakdown and often occurs several months after manufacturing and shipment to the user. It appears that this phenomenon occurs particularly in polyether-based polyurethanes, such as the thick materials used previously, and is apparently caused by the chemical breakdown of these delicately linked compounds.

Gas entrapment, as opposed to the outgassing of volatiles in the compound, occurs to some extent in all mixes, but particularly in the more viscous mixtures. In the thicker mixes a vacuum treatment must be imposed to deaerate the compound. This is both troublesome and wasteful of material and time. Capital investment for vacuum equipment is another consideration.

Bonding of most previously used coatings, expecially epoxies and polyurethanes has been good. RTV rubbers and silicones are exceptions. Bonding of any coating to Teflon or silicone boards is never very successful.

The elastomeric properties combined with the cooefficients of expansion generally favor polyurethanes. Silicones, RTV's and acrylics, although not as elastic, generally are acceptable in this area.

Tear strength, tensile strength, and compression set do not rank high in consideration. Hardness is less significant since the thickness of the

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(2) "Evaluation and Comparative Analysis of Conformal Coating Materials" ESE-E-55 (Oct. 10, 1966) Marshall Space Flight Center, NASA.

thin coating prevents reasonable determination.

4.2 ELECTRICAL CHARACTERISTICS AND TESTS

A number of electrical tests have been performed in the past but it was determined that since the electrical purpose of the coating was generally to insulate and prevent any appreciable change in the electrical characteristics, only the following tests would be required of the coating - as an integral part of the board and circuit - not as a cast plastic compound: change in capacitance buildup (Q-factor), dissipation factor, insulation resistance, and dielectric withstanding voltage.

4.3 CHEMICAL CHARACTERISTICS

Generally, the desirable chemical characteristics are: flame retardancy, chemical stability, low toxicity, fungus resistance, long pot life, long shelf life, low and short curing cycle, low outgassing, and fluorescent. The fluorescence makes it easy to spot voids in the thin clear coating.

5. KSC THIN-FILM COATINGS

We realized that we needed a coating that had a pot-life of 4 to 8 hours; a cure time of about two hours; did not require degassing; could be readily brushed, dipped or sprayed with standard equipment; would not age and shrink appreciably; was thin - approximately 2 mils; was tough and wear resistant yet elastomeric; was relatively moisture and water proof; and was fungus resistant and fluorescent. We surveyed about 30 different possible formulations. Eleven materials were screened and five were fully tested. Two of these were the viscous coatings previously used and the remaining three were thin-film coatings.

Testing was performed by NASA's Marshall Space Flight Center at the request of NASA's Kennedy Space Center (KSC). The tests are reported in reference 2.

Further developed requirements as contained in ESE-E-55 are shown in Table I. Results of the tests are shown in Tables II and III. Qualified materials are listed in KSC-QPL-183-1.[3]

KSC-SPEC-Q-0001 (previously KSC-SPEC-183) was issued as the controlling

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(3) This and other KSC specifications are available from the Kennedy Space Center Library, Specifications and Standards, Kennedy Space Center, Florida 32899.

material specification covering these thin-film materials. KSC-SPEC-E-0001 (previously KSC-SPEC-185) was then issued as the implementing procedural specification. These same materials and several new ones are presently being retested to assure continued compliance.

6. CONCLUSION

To quote from the Abstract of ESE-E-55, "The use of thin film forming materials for conformal coating ESE will eliminate most current production problems, will provide a higher degree of reliability, and will substantially reduce costs." Kennedy Space Center contractors and other groups across the nation have tried these thin film coatings with outstanding success.

An annual cost savings at KSC alone was estimated officially at $240,000. Would the "ferris-wheel" technique using thin-film coatings save you production costs and increase your product reliability? Would this be a boon to you - the electronic engineer?

7. ACKNOWLEDGMENT

Appreciation is expressed to my former colleagues, Mr. W. C. Fussell and Mr. Raymond Flack of Marshall Space Flight Center; and Mr. Norman R. Perry of Kennedy Space Center. My thanks to Anthony Z. Orlowski of the U.S. Army Electronics Command, Fort Manmouth, and his group for their advice and help; and to Edward B. Murphy of MIT's Lincoln Laboratories, George DeYoung of Ames Research Center, the manufacturers of the board material and coatings we used in the testing.

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 $\pm$ 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 circuity
Dissipation factor	0.09 maximum
Insulation resistance	10^{12} ohms minimum at standard conditions; $2x10^{11}$ 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 (Vibration)	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		
	Products Research PR-1538	Hysol PC-22	Magna Coatings 7C 23 WF Laminar X-500	Epoxylite 9653-3	[illegible] Seal CPS-[illegible]
Handling					
Viscosity (N.s/m^2)	10.0	22.0	0.48	0.025	0.150
Coagulation	Solids present	Solids pres.	None	None	None
Cavitation	Bubbles	Bubbles	None	None	None
Application life (hours)	1	0.5	8	5	8
Cure Temperature (^{0}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	Noncorros.
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
Fluorescence	Nonfluorescent	Nonfluoresc.	Highly fluorescent	Highly Flor	Highly Flor

Uncoated Specimens had defects.

TABLE III. ELECTRICAL TEST DATA

			CASTABLE				THIN FILMS					
Test	Condition		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	35.00	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	12.23	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	0.0039	
		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 (a)			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

QUALIFIED PRODUCTS LIST

OF

PRODUCTS QUALIFIED UNDER

JOHN F. KENNEDY SPACE CENTER SPECIFICATION

KSC-C-183

COATINGS, PROTECTIVE, ENVIRONMENTAL, FOR GROUND SUPPORT EQUIPMENT, ELECTRICAL AND ELECTRONIC COMPONENTS

This list has been prepared by the John F. Kennedy Space Center to be used in the KSC procurement of products covered by specification KSC-C-183 and to meet the requirements of MSFC-PROC-293A, Procedure, Coating, Conformal (Polyurethane), Printed Circuit Assemblies. Such listing of a product is not intended to, and does not, connote endorsement of the product by NASA. All products listed herein have been qualified according to the requirements of KSC-C-183. This list is subject to change without notice: revision or amendment of this list will be supplied as necessary. The listing of a product does not release the supplier or contractor from compliance with the specification requirements. Use of the information shown herein for advertising or publicity purposes is forbidden.

The activity responsible for this Qualified Products List is the Technology Office, Quality Assurance Directorate, John F. Kennedy Space Center, Florida.

QUALIFIED PRODUCTS LIST

Manufacturer's Designation	Test or Qualification Reference	Manufacturer's Name & Address
1. CPS-773	Investigation #ESE-E-55	Coast Pro-Seal & Mfg. Company 19451 Susana Road Compton, California Telephone: 213/636-0851
2. Epoxylite 96-53	Investigation #ESE-E-55	Epoxylite Corporation 1428 North Tyler Avenue. South El Monte, California Telephone: 213/444-9514
3. Laminar X-500-7C23WF	Investigation #ESE-E-55	Magna Coating's & Chem. Corp. 1785 Northeastern Los Angeles, California Telephone: 213-261-7111

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