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ABSTRACT

Foam encapsulants are used to encapsulate electromechanical assemblies for reasons such as shock mitigation, structural support, and voltage breakdown protection. Characterization of electrical properties of polymer encapsulants is important in situations where potting materials are in intimate contact with electrical components (e.g., printed wiring boards). REF308, REF320, RSF200, and EF-AR20 foams were developed for encapsulation in some potting applications at Sandia. Select electrical properties were measured for these Sandia encapsulants to characterize them for use in electromechanical potting applications. Dielectric constant with dissipation factors, volume resistivity, and dielectric strength were measured for REF308, REF320, RSF200, and EF-AR20 encapsulants. Fabrication of foam test specimens and the electrical test procedures will be discussed, and electrical testing results will be reported.

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Introduction

Foam encapsulants have been used for many years at Sandia National Laboratories as encapsulants for the protection of electromechanical systems. Recently, several new encapsulants developed at Sandia were qualified for use as potting materials. Physically blown foams REF308, REF320, EF-AR20 and syntactic (i.e., glass microballoon-filled) foam RSF200 have been developed for potting applications at Sandia. REF308 and REF320 are removable epoxy foams with molded densities of 8 lb/ft^3 and 20 lb/ft^3 respectively. EF-AR20 is a conventional epoxy foam with a molded density of 20 lb/ft^3. RSF200 is a removable syntactic foam with a nominal density of 48 lb/ft^3. The formulations and processing for these encapsulants have been previously documented[1,2,3].

Characterization of material properties is required for qualification of these encapsulants for use in Sandia/DOE programs. The characterization of a variety of mechanical, thermal, and electrical properties for these foams have been identified as being necessary for qualification for some important potting applications[4]. Electrical properties of dielectric constant with dissipation factors, volume resistivity, and dielectric strength were measured for REF308, REF320, EF-AR20, and RSF200.

Dielectric constant is the ratio of capacitance of a material to that of free space. It essentially is the measure of the foam's ability to resist the formation of an electric field within it. Measured along with the dielectric constant is the dissipation factor which is the ratio of the power loss in a dielectric material to the total power transmitted, thus it is a measure of the imperfection of the dielectric.

Volume resistivity is a parameter that indicates a material's electrical resistance. The electrical resistance in Ohms (Ω) is measured on a specimen of material with known physical dimensions and is reported in units of Ohm-cm (Ω-cm). Volume resistivity data is valuable for predicting the ability of an encapsulant to behave as an electrical insulator for electrical leads and solder joints in electronic assemblies.

Dielectric breakdown strength is the measure of an insulating material's maximum electrical field strength before the material experiences electrical breakdown. Electrical breakdown may be electric arcing through or around the material. Dielectric breakdown strength is an especially important property for encapsulants used in high voltage applications, such as syntactic foam encapsulants, including RSF200.

Foam Sample Preparation

All foam specimens used in electrical testing were cast in aluminum molds with nominal interior dimensions of 4 inch diameter x 0.25 inch thick, which yielded disc-shaped foams. Since a nominal thickness of 0.125 inch was required for testing, the 4 inch diameter foam discs were machined to a thickness of approximately 0.125 inch.

A total of five discs each were fabricated for REF308, REF320, EF-AR20 and RSF200 foams. After machining, all foam discs were weighed, diameter and thickness were measured, and foam density for each was calculated.

Experimental

All electrical properties on the foams were measured at Plastics Technologies Laboratories, Inc. (Pittsfield, MA). Prior to electrical testing, all samples were conditioned by storing them at 23°C, 50% relative humidity (RH) for a minimum of 40 hours.

Dielectric constant measurements for all foam specimens were performed using method ASTM D150-98, "Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation." Testing was performed at 23°C, 50% RH. Measurements were done at 60 Hz frequency and an applied voltage of 5 volts. Parallel plate electrodes with 2.125 inch diameter (1.75 inch sensing diameter) were used. Three measurements were taken from three individual specimens for each foam.

Volume resistivity of all foams was measured using method ASTM D257-99, "Standard Test Methods for DC Resistance or Conductance of Insulating Materials." Testing was performed at 23°C, 50% RH. Parallel plate electrodes with an electrode area of 22.92 cm^2 were used with an applied voltage of 500 volts and an electrification time of 60 seconds. Three measurements were taken from three individual specimens for each foam.

Dielectric breakdown strength of foams was measured using method ASTM D149-97a, "Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies." Testing was performed at 23°C in an oil medium. The electrode used had a diameter of 0.25 inches. Five dielectric strength measurements were measured for each type of foam.

Results and Discussion

The results of dielectric constant testing of foams are contained in Table 1. The dielectric constant value for each type of foam is the average of three measurements. Observing the average dielectric constants for REF308, REF320, EF-AR20, and RSF200 foams, it is not unexpected that the general trend is for dielectric constant to increase as foam density increases. This is consistent with the fact that void space in foams increases as density decreases, and higher void volume results in lower dielectric constant.

Volume resistivity data for the foams are shown in Table 2. Three measurements for each encapsulant were averaged to yield the reported volume resistivity values. As with dielectric constant, the general trend is that volume resistivity increases with increasing density, particularly with the removable foam encapsulants REF308, REF320, and RSF200.

Dielectric breakdown strengths of the foam encapsulants are reported in Table 3. Breakdown strength values are averaged from five measurements for each material. Although dielectric breakdown was measured for the blown foam encapsulants REF308, REF320, and EF-AR20, it is a much more important property for RSF200, the removable syntactic foam, which is used in some high voltage potting applications. As can be seen in Table 3, the dielectric breakdown strength of RSF200 is significantly higher than that of the lower density blown foams.

Table 1: Dielectric constant with dissipation factors for EF-AR20, REF308, REF320, and RSF200 foam encapsulants.

Foam	Thickness (in)	Specimen dissipation factor	Air dissipation factor at specimen capacitance	**Corrected dissipation factor, D**	Sample capacitance, (pF)	Air capacitance, (pF)	**Dielectric constant, k'**
EF-AR20	0.1320	0.317	0.006	0.311	6.96	4.16	1.67
	0.1255	0.307	0.006	0.301	7.35	4.37	1.68
	0.1298	0.180	0.006	0.174	7.23	4.22	1.71
			AVERAGE:	**0.262**		AVERAGE:	**1.69**
REF308	0.1262	0.047	0.009	0.038	5.14	4.35	1.18
	0.1279	0.044	0.009	0.035	5.28	4.29	1.23
	0.1282	0.043	0.009	0.034	5.24	4.28	1.22
			AVERAGE:	**0.036**		AVERAGE:	**1.21**
REF320	0.1391	0.064	0.007	0.057	6.58	3.95	1.67
	0.1250	0.054	0.007	0.047	6.29	4.38	1.44
	0.1330	0.054	0.008	0.046	5.80	4.13	1.40
			AVERAGE:	**0.050**		AVERAGE:	**1.50**
RSF200	0.1280	0.015	0.004	0.011	10.1	4.29	2.35
	0.1152	0.015	0.003	0.012	10.9	4.76	2.29
	0.1317	0.015	0.004	0.011	9.86	4.17	2.36
			AVERAGE:	**0.011**		AVERAGE:	**2.34**

Table 2: Volume resistivity of EF-AR20, REF308, REF320, and RSF200 foam encapsulants.

Foam	Thickness (in)	Volume resistance (Ω)	Volume resistivity (Ω-cm)
EF-AR20	0.130 0.125 0.129	1.546×10^{10} 1.940×10^{10} 9.717×10^{10}	1.07×10^{12} 1.40×10^{12} 6.80×10^{12}
	AVERAGE:	4.401×10^{10}	**3.09×10^{12}**
REF308	0.125 0.125 0.126	7.933×10^{10} 1.702×10^{11} 2.155×10^{11}	5.73×10^{12} 1.23×10^{13} 1.54×10^{13}
	AVERAGE:	1.550×10^{11}	**1.11×10^{13}**
REF320	0.136 0.125 0.125	1.007×10^{12} 2.719×10^{12} 1.770×10^{12}	6.68×10^{13} 1.96×10^{14} 1.28×10^{14}
	AVERAGE:	1.832×10^{12}	**1.30×10^{14}**
RSF200	0.126 0.111 0.131	9.780×10^{12} 9.057×10^{12} 1.043×10^{13}	7.00×10^{14} 7.36×10^{14} 7.18×10^{14}
	AVERAGE:	9.756×10^{12}	**7.18×10^{14}**

Table 3: Dielectric breakdown strength of EF-AR20, REF308, REF320, and RSF200 foam encapsulants.

Foam	Test number	Failure location on electrode	Thickness (in)	Breakdown voltage (kV)	Dielectric strength (V/mil)
EF-AR20 (tested at 500 V/s)	1	Center	0.128	8.2	64
	2	Center	0.125	8.6	69
	3	Center	0.123	7.9	64
	4	Center	0.129	9.5	74
	5	Center	0.125	12.4	99
		AVERAGE:	0.126	9.3	**74**
		Std. Dev.:	0.002	1.8	15
REF308 (tested at 1000 V/s)	1	Center	0.125	17.3	138
	2	Center	0.124	20.8	168
	3	Center	0.125	21.7	174
	4	Center	0.125	17.1	137
	5	Center	0.124	17.4	140
		AVERAGE:	0.125	18.9	**151**
		Std. Dev.:	0.001	2.2	18
REF320 (tested at 1000 V/s)	1	Center	0.136	19.0	140
	2	Center	0.137	18.0	131
	3	Center	0.121	11.3	93
	4	Center	0.122	9.4	77
	5	Center	0.134	13.7	102
		AVERAGE:	0.130	14.3	**109**
		Std. Dev.:	0.008	4.3	26
RSF200 (tested at 2000 V/s)	1	Center	0.130	47.7	367
	2	Center	0.115	42.7	371
	3	Center	0.117	43.9	375
	4	Center	0.132	45.9	348
	5	Center	0.132	40.8	309
		AVERAGE:	0.125	44.2	**354**
		Std. Dev.:	0.008	2.7	27

Summary

Electrical properties of polymer foam encapsulants are important since they help to indicate how the materials will function as potting materials for electrical and/or electro-mechanical assemblies. REF308, REF320, RSF200, and EF-AR20 foams were developed for encapsulation in some potting applications at Sandia. Dielectric constant with dissipation factors, volume resistivity, and dielectric strength were measured for these encapsulants and the data is included in this report.

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