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Plastics in Engineering

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Third Edition

MACHINE DESIGN
SERIES

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← including this page

21-May-92

Mark,

I hope this helps — sorry that I couldn't find anything better.

— Curt

NUCLEAR REGULATORY COMMISSION

Docket No. 50/348/364 Off'l Exh. No. Staff 85

In the matter of Alabama Power Co. (Farley)

Staff ✓ IDENTIFIED 5-21-92

Applicant RECEIVED

Intervenor REJECTED 5-21-92

Cont'g Off'r 5/1/92

Contractor

Other

Reporter Mark Harvey

Tests for Power Factor: ASTM D-150 "Power Factor and Dielectric Constant of Electrical Insulating Materials" establishes the procedure for determining power factor. The same bridges or susceptance variation methods in a resonant circuit which were applicable to the determination of the dielectric constant

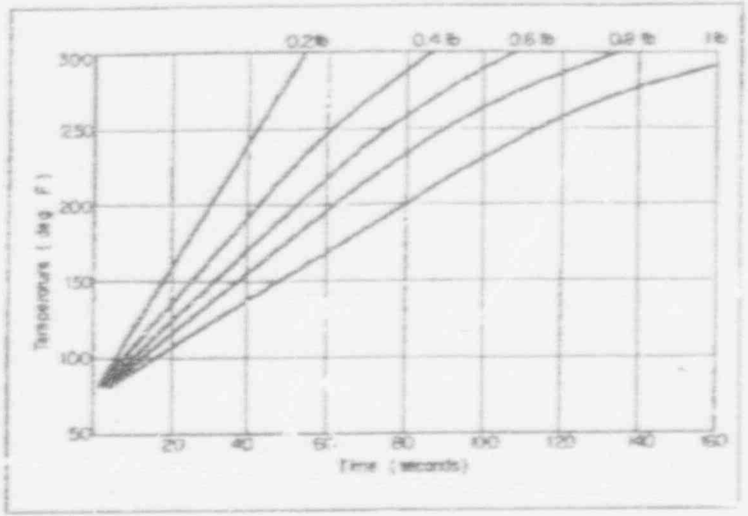

Fig. 48—High-frequency preheating of woodflour-filled phenolic

are employed for the determination of the power factor or the cosine of the dielectric phase angle. (Refer to the section on the dielectric constant for details on the specimen sizes and testing procedures.)

Insulation Resistance

Plastics, like other insulating materials, exhibit a high resistance to the passage of electrical currents. Whereas, the resistance of a good metal conductor may be of the 10^{-6} order of ohm centimeters, the resistance of a good insulator will be 10^{15} order of ohm centimeters. Such quantities are difficult to measure with a high degree of accuracy, and the variations in insula-

tion resistance over a given sample of material are usually of such magnitude as to obviate the development of more accurate instruments. Measurement may be broken down into volume and surface resistance, described as follows:

VOLUME RESISTANCE: The volume resistance between two electrodes is the ratio of the voltage applied to the electrodes to the current which flows through the volume of the insulating material.

SURFACE RESISTANCE: The surface resistance between two electrodes is the ratio of the voltage applied to the electrodes to the current which flows across the surface layers.

On some applications the surface resistivity rather than the volume resistivity proves to be the limiting factor. Dirt and moisture accumulating upon a surface will often tend to lower insulation resistance appreciably. The absorption of water by plastics, particularly those with the outside resin film removed, has seriously reduced the surface resistivity of some of the plastics. Moisture absorption, high temperatures, and presence of carbon black in the filler do not help the insulation qualities. In fact, the insulation resistance of most dielectrics falls off sharply after a certain high temperature is reached. The insulation resistance of typical insulating materials and plastics are compared in TABLE XXXV. The plastics have been measured at approximately 50 per cent humidity at a potential gradient of approximately 1000 volts per inch. It is an interesting, though not unexpected, fact that the dielectric properties of the plastics depend upon their moisture absorption. Those with least absorption are best insulators.

Volume resistivity also is dependent to a great extent upon the filler included in the molding composition. In the case of a filler such as acetylene black the molding composition may in fact be rendered semiconducting. The writer has added small amounts of this filler to standard molding compounds to render them electrically conductive, and preheated them by the passage of electrical current. This same principle has also been applied in rendering rubber compounds electrically conductive.

Surface insulation resistance of most insulators is extremely good under dry conditions, but becomes poor when exposed to damp conditions. Resistance is lowered considerably if the mois-

ture is absorbed into a continuous film, which would occur if salts from the material itself or from dirt on the surface aids the absorption. Some materials like fused quartz, have high volumetric resistivity, but low surface resistivity at high humidities.

TABLE XXXV

Volume Resistivity of Insulating Materials
(25 degrees Cent.)

Material	Ohm-Cms.
Phenol formaldehyde	[illegible]
Urea formaldehyde	[illegible]
Methyl methacrylate	> [illegible]
Polyvinyl chloride acetate	[illegible]
Cellulose acetate and acetate butyrate	[illegible]
Polystyrene	[illegible]
Polyethylene	[illegible]
Polyvinylidene chloride	[illegible]
Rubber	[illegible]
Glass	[illegible]
Fused quartz	[illegible]

Various waxes or materials like polyethylene have high volumetric as well as surface resistivity.

The electrical property most affected by moisture is insulation resistance, which decreases rapidly as foreign conducting material adheres to the surface. When any sample of plastics is placed in 100 per cent relative humidity an ionized conducting film forms quickly, and the insulation resistance drops until an equilibrium value is reached. Field determined these values for a number of plastics, listed in TABLE XXXVI.* Quite surprising is the high position of cellulose acetate-butyrate, attributed to the water lying in discontinuous pockets:

TABLE XXXVI

Effect of Moisture on Electrical Resistivity

Material	Equilibrium Surface Resistivity at 100% R.H. (ohms)
Cellulose acetate butyrate	20 × [illegible]
Silicone rubber	10 × [illegible]
Polytetrafluoroethylene	[illegible] × [illegible]
Polystyrene, sheet	[illegible] × [illegible]
Polydichlorostyrene	[illegible] × [illegible]
Ethylcellulose	[illegible] × [illegible]
Phenolic, mica filled	[illegible] × [illegible]
Glazed porcelain	[illegible] × [illegible]
Polyethylene	[illegible] × [illegible]
Phenolic laminate, Type XX	[illegible] × [illegible]

When high moisture conditions prevail on the surface of a plastic, the opportunity for fungi growth is enhanced, and there

*R. F. Field—Plastics & Resins—4, 9, Sept., 1945.

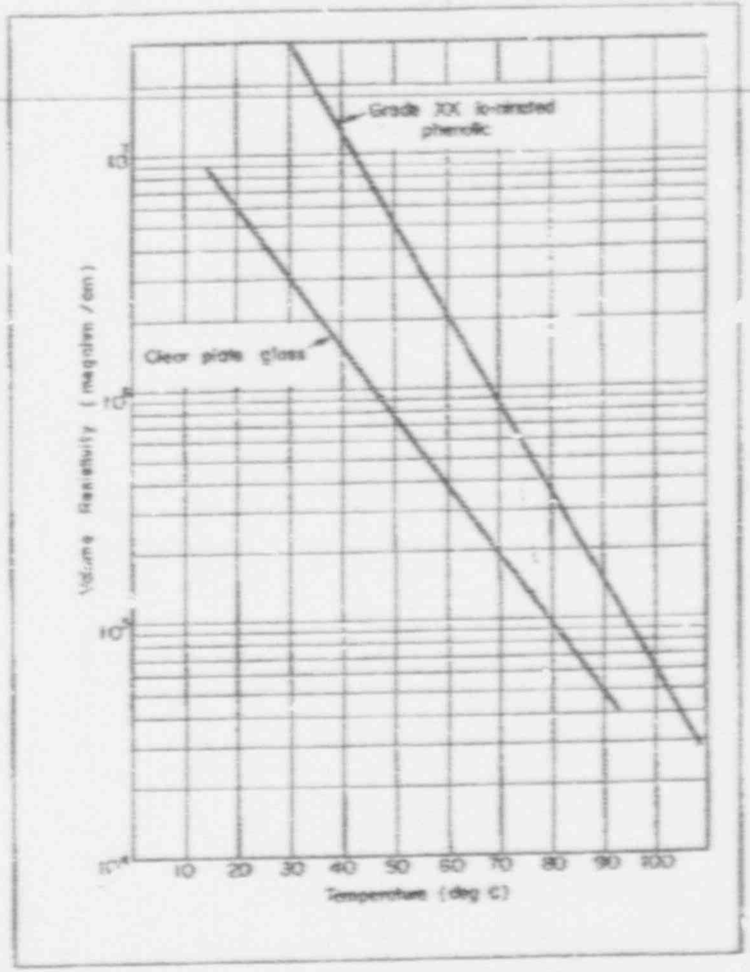

Fig. 49—Curves show how volume resistivity varies with temperature

have been numerous instances reported where this growth has developed on the surface of the plastic. The plastic itself was not affected, though the effects of the fungi growth were to lower surface insulation resistance appreciably.

No other characteristic varies as much with temperature as

volumetric resistivity. This is quite important for organic plastics which, as electrical insulation, experience a temperature rise in the operation of electrical equipment. Data which illustrates the variation of volume resistivity with temperature is illustrated in *Fig. 49*, taken from a paper by Albert**.

Tests for Insulation Resistance: The ASTM specification D-257 "Tests for Resistance of Electrical Insulation" outlines a standardized procedure for conducting resistivity tests which should be heeded by the manufacturers. One of the best methods for determining high insulation resistance is through capacitor discharge methods and galvanometer deflection. Voltage from a battery is applied across a circuit with an unknown capacitor. A universal shunt across the galvanometer is adjusted until a full scale reading is obtained. The capacitor is then shorted to discharge it fully. Test voltage is applied to capacitor again and after a certain time has elapsed the galvanometer deflection is measured. Proportioning of galvanometer deflections and elapsed time will give values

TABLE XXVII

Time Cycle for ASTM Arc Test

Current (milliamperes)	Time Cycle	Heat Generation Approx. (watts)	Total Time (seconds)
10	¼ sec. on-1¾ sec. off	2	60
10	¼ sec. on- ¾ sec. off	4	120
10	¼ sec. on- ¼ sec. off	11	180
10	continuous	24	240
20	continuous	34	300
30	continuous	45	360
40	continuous	56	420
50	continuous	67	480
60	continuous	79	540
70	continuous	91	600
80	continuous	102	660
90	continuous	113	720
100	continuous	125	780

of insulation resistance. *For low insulation resistance*, a portable voltmeter connected in series with the insulation resistance across the test voltage has enough sensitivity to measure leakage currents.

Determinations of surface resistances of plastics are to be made on specimens maintained in a definite humidity for 48 hours. In the case of laminated plastics, volume resistance measurements parallel and perpendicular to the laminations should be made. Materials for electrodes are relatively unimportant, as long as

**G. Albert—Plastics—2, 32, June, 1945.

good contact with the insulating material is made.

There are other methods of test which evaluate the effects of low insulation resistance. These are known as leakage tests and are performed upon completed assemblies of electrical units such as motors, transformers, soldering irons, etc. After the part has been brought to operating temperature, which may also involve simultaneous exposure to high humidity, the electrical current leakage between the live or conducting part of the circuit and the frame or nonconducting portion of the motor is measured. If excessive, such that an electrical shock hazard exists, the unit is condemned.

Arc Resistance

A rather important electrical characteristic of plastics is their arc resistance. This property is significant to units such as switches or circuit breakers, when electrical current may form an arc in the immediate vicinity of the surface of the plastic. The intensity of this spark or arc depends not only upon voltage but also upon electrical current, and when the switch is slow acting (not the snap-action type of switch) the effects upon the plastic may be quite severe. In fact, those materials which behave best are those which have appreciable amounts of water adsorbed on the surface, and which are capable of delivering up copious quantities of non-ionized water vapor to quench the arc. Vulcanized fiber and shellac are two materials with good arc resistance. Their insertion into electrical molded parts such as phenolics, aid the latter in their arc resistance.

Thermoplastics such as polystyrene and acrylics possess fair arc resistance, not carbonizing in the presence of an arc, though showing a tendency to sear on the surface due to loss of volatiles formed on decomposition. On the other hand, the burned carbonized deposit formed on phenolic molded parts is definitely a handicap to good arc resistance. Urea or melamine formaldehyde molded parts on the other hand, possess good arc resistance, and are generally specified to fulfill this requirement. These plastics have been particularly serviceable on ignition distributor housings exposed to high voltages and high altitudes, a combination which causes most phenolics to arc or track badly across the surface.

Tests for Arc Resistance: ASTM D-495 "Arc Resistance of

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Handbook of Plastics and Elastomers

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There are several chemical variations of diallyl phthalate resins, but the two most commonly used are diallyl phthalate (DAP) and diallyl isophthalate (DAIP). The primary application difference is that DAIP will withstand somewhat higher temperatures than will DAP. The retention of electrical-resistance properties after humidity conditioning is compared in Fig. 10 for several glass-filled DAP, DAIP, epoxy, and phenolic compounds, and one mineral and glass-filled epoxy. Electrical properties of various molding compounds are given in Table 16.

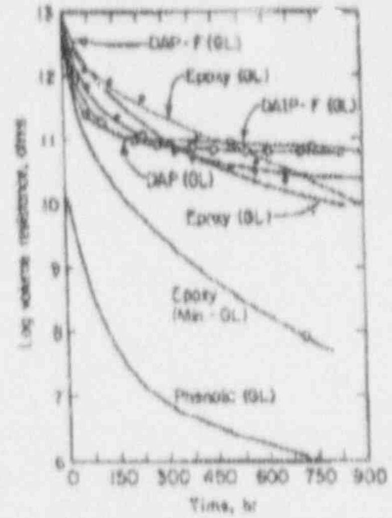

Fig. 10 Volume resistance decrease of several thermosetting materials at 70°C and 100 percent RH. (GL indicates glass filler, and Min-GL indicates mineral and glass filler.)[11]

The excellent dimensional stability of diallyl phthalates has been mentioned above. This is demonstrated in Fig. 11, which compares diallyl phthalates with other plastic materials at various temperatures.

Likewise, the excellent electrical properties of diallyl phthalates have been stressed. The effect of frequency and temperature on dielectric constant is shown in Fig. 12, the effect of frequency and temperature on dissipation factor in Fig. 13. The characteristics of DAP, epoxy, and phenolic compounds as a function of temperature are presented in Fig. 14. Diallyl isophthalate (DAIP) is also especially good in retention of dielectric strength, as indicated in Fig. 15. Diallyl phthalates rate high among plastics in resistivity levels, and the resistivity data for a variety of plastics and other materials were shown earlier in Fig. 1 and Table 4. Dielectric strengths of certain DAP and alkyds rate high, as shown in Fig. 16. Drastic reductions may occur above 80 percent humidity, however.

TABLE 16 Properties of Various Diallyl Phthalate Molding Compounds

Property	Orlon	Dacron	Long glass	Asbestos	Short glass	Short glass*
Tensile strength, lb/in.²	5,000	6,000	10,000	5,500	7,000	7,000
Compressive strength, lb/in.²	25,000	25,000	25,000	22,000	25,000	28,000
Flexural strength, lb/in.²	10,000	11,000	16,000	9,000	13,000	12,000
Flexural modulus, lb/in.² × 10⁻⁶	[illegible]	0.64	1.8	1.2	1.2	1.3
Impact strength, Izod, ft-lb/in. of notch	1.5	4.5	6.0	0.4	0.5	0.5
Hardness, Rockwell M	108	108	109	107	108	110
Specific gravity at 25°C	1.31–1.45	1.29–1.62	1.65–1.70	1.55–1.63	1.6–1.8	1.65–1.75
Dielectric constant:						
At 1 kHz	3.7–4.0	3.79	4.5	....	4.4	4.1
At 1 MHz	3.3–3.6	3.4	4.2	4.5–6.0	4.1	[illegible]
Dissipation factor:						
At 1 kHz	0.030–0.035	0.008	0.008–0.006	0.04–0.08	0.006	0.004
At 1 MHz	0.015–0.020	0.012	0.008	0.04–0.06	0.008	0.008
Mold shrinkage, in./in.	0.009	0.010	0.007	0.006	0.004	0.006
Postmold shrinkage, in./in.	0.001	0.0005	0.0007	0.001	0.0007	0.0005
Heat-deflection temperature, °F	285	260	325	325	400	500+
Heat resistance, continuous, °F	300–350	350–450	350–400	350–400	350–400	450

* Based on diallyl isophthalate.

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percent humidity, however,

Compounds

Asbestos	Short glass	Short glass*
8,500	7,000	7,000
12,000	25,000	25,000
9,500	12,000	12,000
1.2	1.2	1.2
0.4	0.4	0.5
100	105	110
1.55–1.65	1.6–1.8	1.66–1.79
....	4.4	4.1
4.5–5.0	4.4	3.4
0.04–0.08	0.006	0.004
0.04–0.06	0.008	0.002
0.008	0.008	0.003
0.001	0.0007	0.0002
325	400	500+
350–400	350–400	450

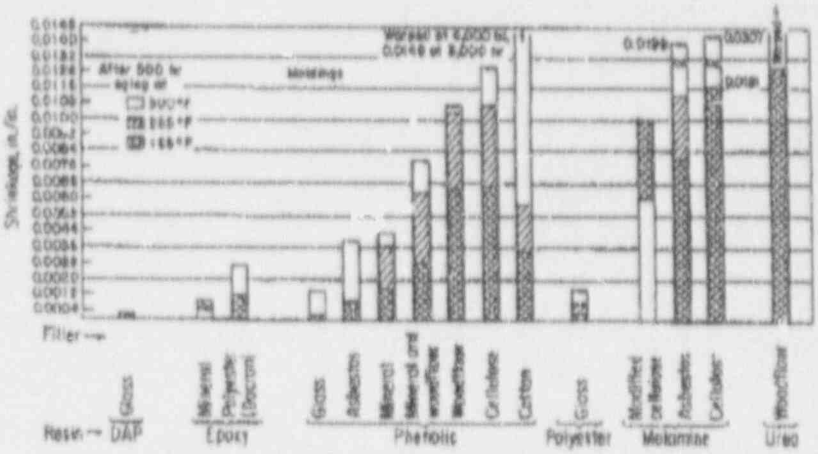


Fig. 11 Shrinkage of various thermosetting molding materials as a result of heat aging.[3]

Epoxies

Epoxies are among the most versatile and most widely used plastics in the electronic field—primarily because of the wide variety of formulations possible, and the ease with which these formulations can be made and utilized with minimal equipment requirements. Formulations range from flexible to rigid in the cured state, and from thin liquids to thick pastes in the uncured state. Conversion from uncured to cured state is accomplished by use of hardeners and/or heat. The largest applications of epoxies in electronics are in embedding applications (potting, casting, encapsulating, and impregnating), molded products, and laminated constructions such as metal-clad laminates for printed circuits and unclad laminates for various types of insulating and terminal boards.

Basically, epoxies are available as liquid or solid resins, and as powdered molding compounds. The molding compounds, while broadly used for embedment of electronic assemblies by the transfer-molding technique, are also employed for transfer and compression molding of many other types of electrical parts. Typical properties of glass-fiber-filled and mineral-filled molding compounds are given in Table 17. Physical and electrical properties are generally very stable in humid environments, although resistance properties in humidity are dependent on the filler used, to some extent, as shown in Figs. 17 and 18. Also, although the general electrical properties of epoxies are good, they are not as good as those of diallyl phthalates as a function of either temperature or humidity. This is shown in Figs. 10 and 14.

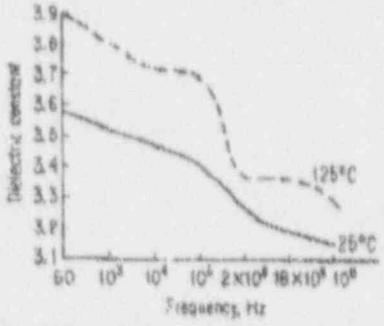


Fig. 12 Effect of frequency and temperature on the dielectric constant of unfilled diallyl phthalate.[3]

In addition to their versatility and good electrical properties, epoxies are also outstanding in their low shrinkage, their dimensional stability, and their adhesive properties. Their shrinkage is often less than 1 percent, and the as-molded dimensions of an epoxy part change little with time or environmental conditions, other

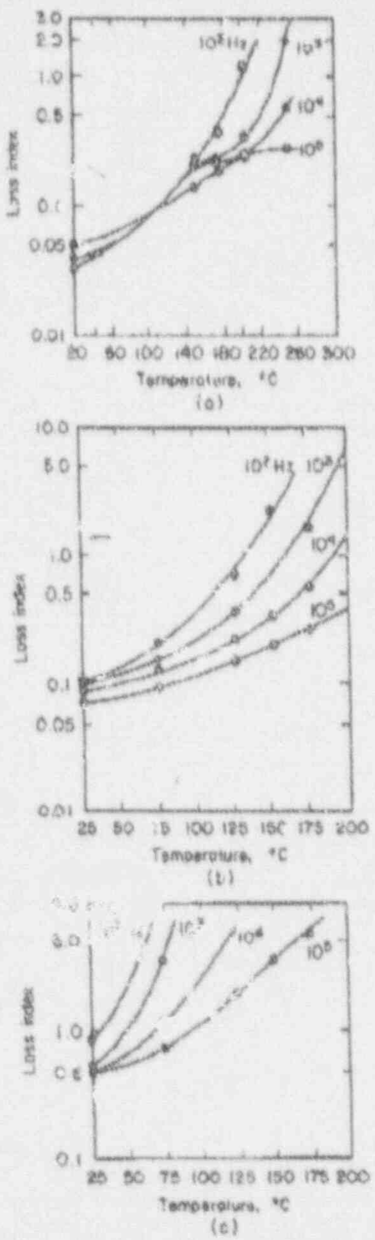


Fig. 14 Loss index vs. temperature and frequency for (a) glass-filled diallyl phthalate (DAP) compound, (b) mineral and glass-filled epoxy compounds, and (c) glass-filled phenolic compound.[13]

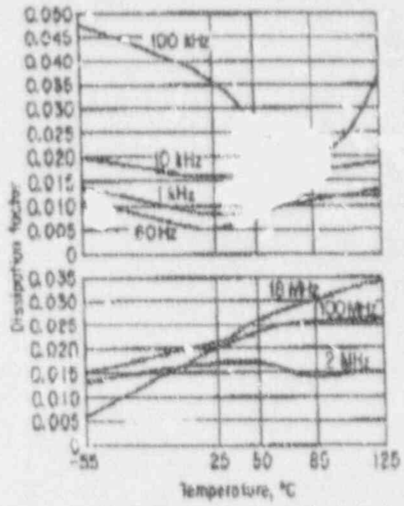


Fig. 13 Effect of frequency and temperature on the dissipation factor of unfilled diallyl phthalate.[13]

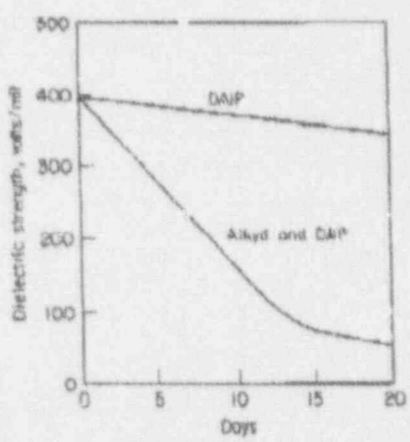
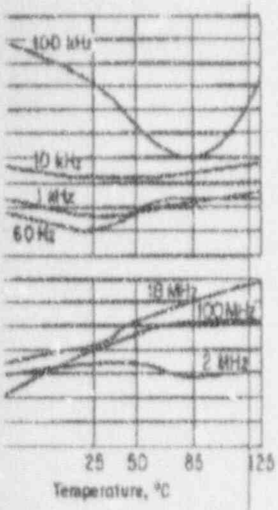


Fig. 15 Effect of heat aging at 400°F on the dielectric strength of diallyl phthalate (DAP), diallyl isophthalate (DAIP), and alkyd molding materials.[14]



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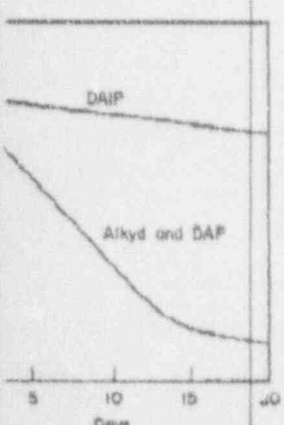

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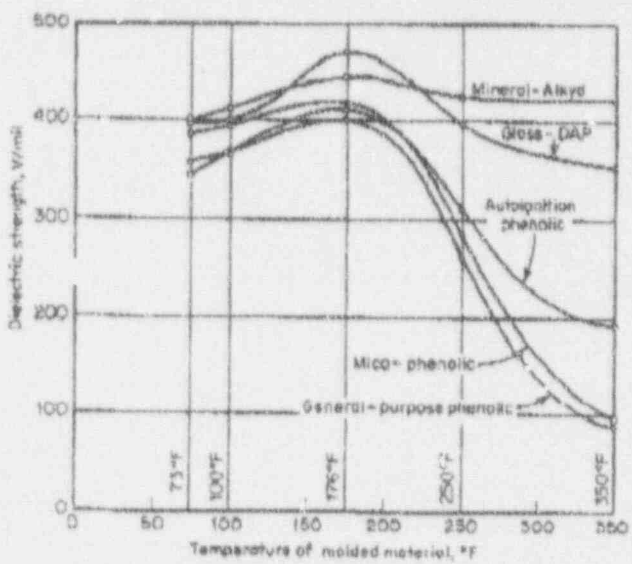

Fig. 16 Dielectric strength of various molding compounds as a function of temperature.[11]

TABLE 17 Typical Properties of Epoxy Molding Compounds with Various Fillers

	Glass-fiber filler	Mineral filler
Tensile strength, lb/in.²	14,000–30,000	5,000–7,000
Elongation, %	4	
Tensile modulus, 10⁵ lb/in.²	30.4	
Compressive strength, lb/in.²	25,000–50,000	18,000–25,000
Flexural strength, lb/in.²	20,000–26,000	10,000–15,000
Impact strength, Izod, ft-lb/in. of notch	8–15	0.26–0.45
Hardness, Rockwell	M100–M108	M101
Specific gravity	1.8–2	1.6–2.00
Thermal conductivity (cal)(cm)/(s)(cm²)(°C)	$7–10 \times 10^{-4}$	$7–18 \times 10^{-4}$
Specific heat per °C	0.19	
Coefficient of thermal expansion, per °C × 10^{-5}	1.1–3	2.4–5
Heat resistance, continuous, °F	330–500	300–500
Heat-distortion temp, °F	400–500	250–450
Volume resistivity, Ω-cm	3.8×10^{15}	9×10^{15}
Dielectric strength, ⅛-in. (V/mil):		
Short-time	360	380–400
Step by step	340	380
Dielectric constant at 60, 10³, and 10⁶ Hz	4–6	4–5
Arc resistance, s	125–140	150–180
Burning rate	Self-extinguishing	Self-extinguishing
Water absorption, %*	0.05–0.095	0.1

* Test performed on ⅛-in.-thick piece immersed in distilled water for 24 h at room temperature.

than excessive heat. Their excellent performance in this respect is shown in Fig. 11. Because of the low shrinkage and good strength properties of epoxies, cured epoxy parts resist cracking, both upon curing and in thermal shock, better than most other rigid thermosetting materials. Based on the excellent bonds obtained with epoxy resins to most substrates, epoxy formulations are broadly used as adhesives. Even when not specifically used as adhesives, the bonding properties of epoxies often provide a better seal around inserts, terminals, and other interfaces than do most other plastic materials.

Phenolics

Phenolics are among the oldest, best-known general-purpose molding materials. They are also among the lowest in cost and the easiest to mold. An extremely large number of phenolic materials are available, based on the many resin and filler combinations. Some grades are general-purpose, medium- and high-impact, electrical-insulation, heat-resistant, moisture-resistant, arc-resistant, and injection-molding grades.

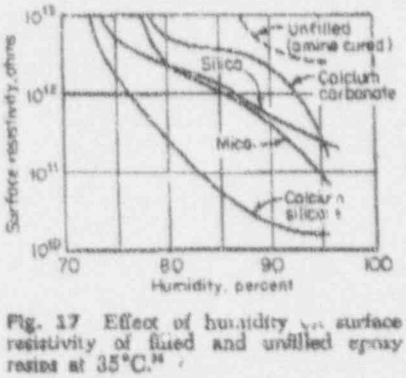

Fig. 17 Effect of humidity on surface resistivity of filled and unfilled epoxy resins at 35°C.[16]

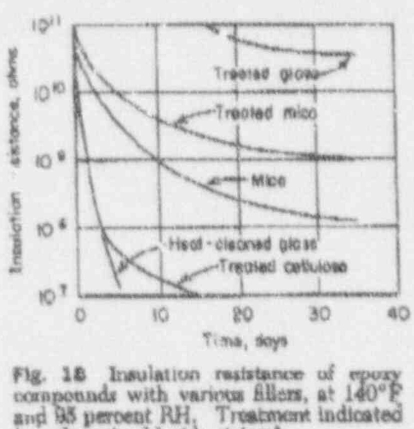

Fig. 18 Insulation resistance of epoxy compounds with various fillers, at 140°F and 95 percent RH. Treatment indicated is a chromic chloride sizing.[8]

Although it is possible to get various grades of phenolics for various applications, phenolics, generally speaking, are not equivalent to diallyl phthalates and epoxies in resistance to humidity, shrinkage, dimensional stability, and retention of electrical properties in extreme environments. Critical electrical-property comparisons are shown in Figs. 10 and 14. Phenolics are, however, quite adequate for a large percentage of electrical applications. Furthermore improved grades have been developed which yield considerable improvement in humid environments (Fig. 19) and at higher temperatures (Fig. 20). In addition, the glass-filled, heat-resistant grades are outstanding in thermal stability up to 400°F and higher, with some being useful up to 500°F. Phenolics are relatively stable, physically, as discussed in Chap. 1. Shrinkage in heat aging varies over a fairly wide range, depending on filler used. Glass-filled phenolics are the more stable, as shown in Fig. 11.

Polybutadienes

This is a versatile family of thermosetting plastic materials having excellent electrical properties which are stable at high frequencies and elevated temperatures. Further, these materials offer low moisture absorption, excellent chemical resistance, and excellent thermal stability among plastic materials. Polybutadienes are fast-curing, and can be molded, laminated, or used as casting and potting materials. They can even be injection-molded, which is the fast molding technique used for thermoplastics. This can be desirable, owing to lower processing costs for volume production. While the nature of the polymerization is such that most thermosets cannot be injection-molded, considerable effort has recently been devoted to development

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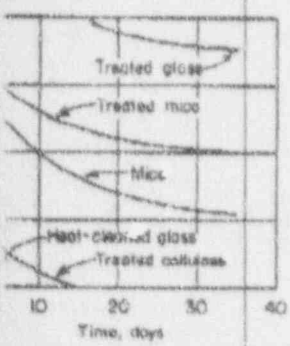

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...terials having excellent elec- ...and elevated temperatures. ...xcellent chemical resistance, ... Polybutadienes are fast- ...and potting materials. They ...technique used for thermo- ...ng costs for volume produc- ...that most thermosets cannot ...en devoted to development

of injection-moldable thermosetting plastics. Table 16 shows representative properties of polybutadiene molding compounds, for a one-component system with excellent shelf life. Figures 21 and 22 show the dielectric constant and dissipation factor of glass-reinforced polybutadiene laminates up to 500°F.

Polyesters

Polyesters are versatile resins, which handle much like the epoxies. They are available in forms ranging from low-viscosity liquids to thick pastes or putties. The liquids are used for embedding applications and laminated products, much like the epoxies, and the pastes are used for molding applications. Although both epoxies and polyesters are available in formulations for room-temperature cure and formulations for heat cure, the chemical curing mechanism, or polymerization mechanism, is different for the two types of resins. Likewise, of course, the basic resins are chemically different. It is their physical forms and application forms which make them similar.

The major advantages of polyesters over epoxies are lower cost and appreciably lower electrical losses for the best electrical-grade polyesters. Some im-

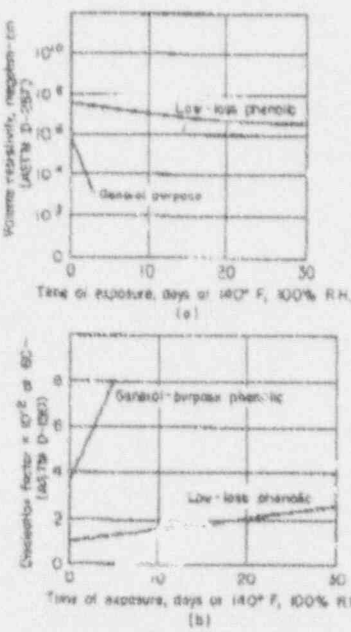

Fig. 19 Comparison of humidity effects on (*a*) volume resistivity and (*b*) dissipation factor for a general-purpose and a low-loss phenolic compound.[11]

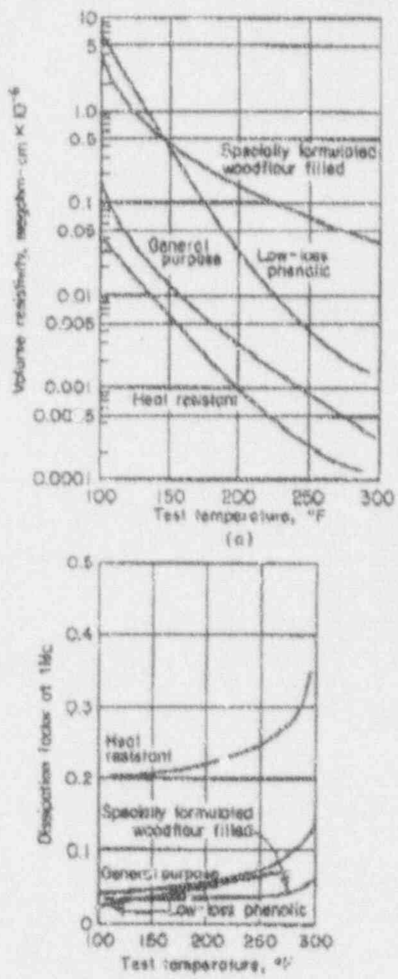

Fig. 20 Comparison of temperature effects on (*a*) volume resistivity and (*b*) dissipation factor for several grades of phenolic compounds.[11]