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REMOVABLE FOAM ENCAPSULANTS

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Abstract

This paper describes the use of two different expandable bead foams as solvent removable encapsulants; specifically they are polystyrene (STYROPOR BF-414, BASF Wyandotte) and a styrene-maleic anhydride copolymer (DYTHERM X214, ARCO/Polymers). These expandable bead foams are commercially available and normally used in insulating applications. However, we have adapted them to the unusual task of encapsulating sophisticated and expensive electronic hardware which requires a rework capability. Most encapsulating materials are crosslinked and, therefore, difficult to penetrate either by mechanical means or solvent attack. Usually these approaches result in component damage. The respective foams processing, resultant properties and removal methods are discussed in detail in this paper.

By a pre-expansion technique, foam densities ranging from 0.10 to 0.60 cm^3 can be achieved which provide the design engineer with a wide latitude of densities and mechanical properties for material selection. The polystyrene has an upper use temperature of about 80°C while the styrene-maleic anhydride copolymer improves this capability to 11~~5~~9°C. Since the foams are thermoplastic, removal can be achieved with solvents such as toluene with little or no component damage. Functional electronic components have been successfully potted and depotted in manufacturing situations. The rework capability these materials and processes have provided has resulted in sizable cost savings for the DOE.

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1. INTRODUCTION

In the defense industry, expensive and complex electronic hardware often requires encapsulation for environmental protection. Frequently it is desirable to remove the encapsulant for failure analysis and/or rework. Unfortunately, most existing encapsulants are crosslinked systems like epoxy resins which are difficult to remove either by mechanical means or solvent attack. Usually these approaches result in component damage. To overcome this problem, we have developed two removable encapsulants based on commercially available expandable bead foams. Specifically, one is a polystyrene bead foam (STYROPOR BF-414, BASF Wyandotte) and the other is a styrene-maleic anhydride copolymer (DYTHERM X214, ARCO/Polymers). Since these foams are thermoplastics, they are solvent removable. The primary advantage of these encapsulants is economic; they allow a component rework capability, thereby saving replacement costs.

Expandable polystyrene beads have been on the market since the early 1950s whereas the DYTHERM copolymer has only become available recently. Typically these materials are used in packaging and insulation applications; however, we have adapted them to the unusual task of encapsulating sophisticated electronic hardware. For encapsulation purposes, we have selected small bead size material for better filling characteristics (500-800 μ dia.). The beads contain a blowing agent (5-7% pentane) which will cause the beads to expand and fuse upon reaching the polymers softening point. By a pre-expansion technique, foam densities ranging from 0.10 to 0.65 g/cm^3 can be achieved which provides the design engineer with a wide latitude of densities and mechanical properties for material selection. This paper will describe the processing, resultant properties, advantages and disadvantages of each foam encapsulant with emphasis on the DYTHERM material since the STYROPOR material has been reported.(1,2)

2. POLYSTYRNE BEAD FOAM (STYROPOR)

2.1 Processing

Different foam densities and therefore different mechanical strength foams can be achieved by a pre-expansion technique. As previously mentioned, densities can be varied from about 0.1 to 0.6 g/cm^3; the details of this process can be found elsewhere.(2) In general, the beads are heated, unconstrained above their softening temperature (~80°C), causing the beads to expand to a predetermined volume. The time necessary for the beads to attain a given volume varies depending on the the expansion temperature, pentane content and volume of beads. Once the beads have reached the desired volume, they are immediately removed from the heat, rapidly dropping the temperature through the softening point so that further expansion cannot take place. Since it is virtually impossible to get all the beads to expand at the same rate to a given size or volume, the pre-expanded beads are screened to ensure a uniform material.

In our potting applications, a suitable mold was constructed to house the electronics. In many instances the housing was an integral part of the assembly. The mold should have a convenient opening for ease of filling. Potting simply consists of pouring the appropriate density beads into the unit which is being vibrated to insure complete fill. Once filled, the opening is sealed and the unit placed in a 95°C circulating air oven. Since units vary in size, the time required for expansion and fusion will vary. The time needed for encapsulating a given unit can be determined by placing a thermocouple in the geometric center of the unit (last place to heat up). When the center has been maintained at 95°C for approximately 5 minutes, fusion is complete. Since this foam is an excellent insulator, subsequent cooldown should be done slowly to avoid any undue stress buildup or shrinkage because of large temperature gradients.

2.2 Physical Properties

Resultant physical properties of the encapsulant will vary with density, especially mechanical strength. Figures 1 & 2 show compressive strength and modulus of STYROPOR BF-414. As shown, compressive strength can be varied from about 0.69 to 9.65 MPa by changing the density from 0.13 to 0.48 g/cm^3 respectively. Electrical properties appear to change very little with foam density, typical volume resistivity measurements being 10^{16} to 10^{17} ohm-cm. Moisture absorption is less than 1% for densities of 0.1 to 0.6 g/cm^3. An important consideration in the encapsulation of electronic hardware is the coefficient of thermal expansion. This parameter changes very little from the lowest density foam to pure polystyrene ($4\text{-}7 \times 10^{-5}$ in/in°C). In actual application the lowest density foam capable of supporting applied loads is the most desirable because lower stresses are generated during subsequent temperature cycling. This phenomenon can be demonstrated with the following relationship: $\sigma = E\alpha\Delta T$ where σ = stress, E = Young's modulus, α = coefficient of thermal expansion and ΔT = temperature change. For example, a low modulus, low coefficient of thermal expansion material such as polystyrene bead foam imparts a lower stress buildup during thermal cycling compared to an high modulus epoxy resin. Therefore, the working life of components, solder joints, etc., should be prolonged with the use of polystyrene bead foams as a structural support. Experimental data have been obtained to demonstrate this effect.(3)

2.3 Depotting

Depotting of the polystyrene bead foam is the primary advantage of this material concept; in this work toluene was used. Units were immersed in a vigorously agitated solvent bath at ambient temperature until the polystyrene was completely dissolved. The time it takes to dissolve the polymer depends on the surface area exposed, amount of polymer and polymer density. Larger volumes and denser foams may require fresh solvent because of polystyrene saturation. After depotting, units were washed with fresh toluene followed by acetone. After washing, units are heated to 71°C for 6-8 hours to remove any traces of toluene. If any "wicking" is suspected in components, it is advantageous to bake-out the entire unit under reduced pressure.

There are some important limitations to consider before one adapts polystyrene bead foam to a specific application: (1) polystyrene is a thermoplastic polymer, hence, its upper use temperature is limited to about 85°C (onset of glassy region); (2) polystyrene bead foam has limited strength compared to an epoxy resin; (3) the bead foam has poor bonding characteristics and therefore may not be suitable in high voltage standoff situations; (4) finally, one must bear in mind that exposure to toluene may cause damage to other polymeric materials. In our experience many polymeric materials survive depotting with negligible damage, however, rubbers of all varieties have poor resistance. In any event, we have found it less costly to replace a couple components than an entire unit.

3. STYRENE-MALEIC ANHYDRIDE BEAD FOAM (DYTHERM)

3.1 Processing

Caps Dytherm X214 is a random copolymer of styrene and maleic anhydride manufactured by ARCO/Polymers. Caps Dytherm's primary advantage is extending the upper use temperature of removable foam materials. Polystyrene bead foam encapsulants have been successfully employed in several weapon designs; however, polystyrene bead foam has an upper use temperature limitation of about 85°C. Since an increased number of advanced designs dictate higher use temperatures, efforts have been made to adapt the DYTHERM copolymer to this need. The glass transition temperature, Tg, of this material is 120°C (via TMA) compared to 100°C for polystyrene. Therefore, we expect this material to have adequate mechanical strength to about 110-112°C which satisfies many of our upper temperature requirements.

DYTHERM is an extruded copolymer, consequently, the particles appear "drum-shaped" about 1 mm in diameter and 1 mm long. This particle size is about 2-3 times larger than the spherical polystyrene bead potting material. DYTHERM also contains pentane as the blowing agent and as such is processed much like the polystyrene beads. Again a pre-expansion technique is used to achieve the desired foam density. To pre-expand the DYTHERM material, the beads are placed unconstrained in a 125°C oven for a predetermined time. This process allows the beads to expand to a desired new volume and resultant density (see Ref. 2 for details). Since the beads are irregular shaped, a screening step was not used. Encapsulation of an electronic assembly is accomplished exactly as done with the polystyrene bead homopolymer. Inasmuch as DYTHERM materials have higher softening temperatures than the polystyrene, higher fusion temperatures are necessary. Typically, DYTHERM fusion temperatures are about 125-127°C; the length of time at this temperature varies depending upon the component geometry and amount of DYTHERM required.

3.2 Physical Properties

Mechanical and electrical properties of finished product have been fully characterized but limited space will allow only partial reporting. In general, the physical properties of DYTHERM materials are very comparable to those of polystyrene bead foam. Figure 3 shows a compressive strength comparison of DYTHERM X214 with the polystyrene STYROPOR BF414 product. The copolymer has a slightly higher compressive strength at a given density than the homopolymer. Although not shown, the moduli are comparable. Creep data, tensile strengths and compression set have been determined on DYTHERM materials. Coefficient of thermal expansion is virtually identical with the polystyrene foam ($4\text{-}6 \times 10^{-5}$ in/in/°C). Compared to the polystyrene foam, DYTHERM has slightly better bonding characteristics. Water absorption is less than 0.5% by volume. Electrical properties of molded DYTHERM are shown in Table I. These properties are not only a function of density but how well the copolymer is fused. Poor bead fusion would show marked deterioration in these electrical parameters, in fact, electrical properties could be used as a guide to proper bead fusion. As shown properly fused DYTHERM is an excellent dielectric.

Infrared spectra of the material indicates not only anhydride absorption bands at 1860 and 1780^{-1} cm but a carboxyl band at 1715^{-1} cm. Some hydrolysis of the anhydride apparently occurs in polymer production to account for the presence of organic acid. More importantly, the possibility exists of further anhydride hydrolysis during aging to yield carboxylic acid groups. This aging phenomenon could result in an encapsulant with corrosive properties. To ascertain whether hydrolysis can take place to any appreciable extent, an accelerated aging study was conducted. The study consisted of isothermally aging DYTHERM X214 films at 23°C, 60°C and 70°C, and 50% RH, respectively. These films were analyzed via infrared to determine whether there were any increases in the acid absorption or decreases in the anhydride content. This study lasted 14 months with no appreciable changes in functional group intensities. Thus, we concluded that the copolymer was hydrolytically stable and would not pose a serious corrosion problem to electronic hardware.

3.3 Depotting

Depotting is accomplished similar to that previously described for polystyrene, except that polar solvents such as tetrahydrofuran (THF) and methylene dichloride are recommended for foam removal. Toluene is not effective in DYTHERM removal. After depotting units are washed with acetone and baked-out at 71°C for a minimum of 6 hours.

As with the polystyrene foam, several considerations must be addressed before selecting DYTHERM bead foams as removable encapsulants: (1) because of the larger bead sizes, the filling of very small areas may not be as good as the polystyrene beads; (2) higher fusion temperatures are required for DYTHERM (~125°C), thus individual components must withstand this temperature which is usually 1-2 hours; (3) polar solvents such as THF may be more damaging than toluene toward polymeric materials, therefore care must be taken in evaluating the compatibility of the solvent with other materials.

4. SUMMARY AND CONCLUSIONS

Two thermoplastic removal foam encapsulants have been developed and successfully used for the encapsulation of electronic packages. The polystyrene foam homopolymer has an 85°C upper use temperature limitation. The styrene-maleic anhydride copolymer extends the upper use temperature range to about 110°C. Both foam systems can be made in a wide range of densities and mechanical properties and subsequently removed with an appropriate solvent with little or no damage to components. The rework cycle can be repeated several times. These new potting techniques have resulted in considerable cost savings by allowing a rework capability for complex electronic hardware.

5. REFERENCES

1. K. B. Wischmann, R. A. Assink, SAMPE Jour. Vol. 13, No. 2, P. 15, 1977
2. D. J. Fossey, C. H. Smith, K. B. Wischmann, J. Cellular Plastics, Vol. 13, No. 5, p. 397, 1977
3. J. W. Munford, IEE Trans. on Parts, Hybrids and Packaging, Vol. PH-P-11, No. 4, p. 296, 1975

6. ILLUSTRATIONS

6.1 Tables

TABLE I

ELECTRICAL PROPERTIES, MOLDED DYTHERM

Dielectric Constant, E	10.8 (.11 g/cc)	15.3 (.16g/cc)	24.3 (.26g/cc)
Freq. 10^3	1.186	1.296	1.487
10^4	1.186	1.295	1.484
10^5	1.185	1.294	1.481
10^6	1.184	1.297	1.478
Dissipation Factor, D			
Freq. 10^3	-	-	-
10^4	.0006	.0008	.0021
10^5	.0006	.0010	.0015
10^6	.0008	.0014	.0018
Volume Resistivity, ρ ohm-cm			
500 volts	-	5.02×10^{17}	9.33×10^{16}
1000 volts	1.26×10^{18}	1.17×10^{18}	9.60×10^{16}

6.2 Captions-Graph Axes-Legends

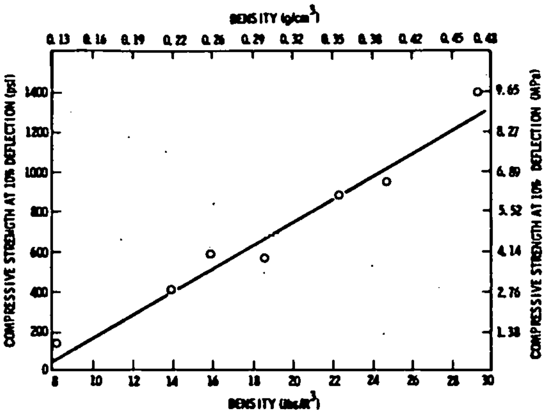

Fig. 1. Compressive Strength Versus Density of Polystyrene Bead Foam.

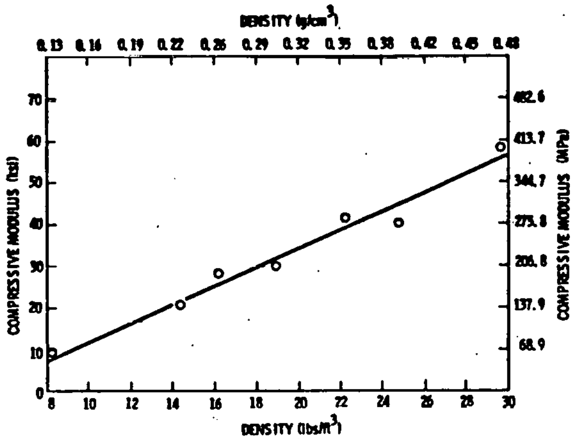

Fig. 2. Compressive Modulus Versus Density of Polystyrene Bead Foam.

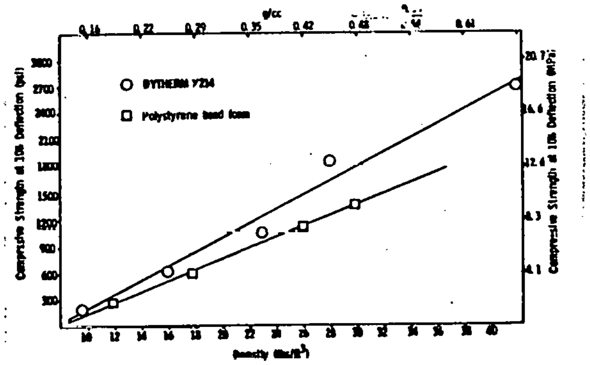

Fig. 3. Compressive Strength of ARCO Polystyrene-Maleic Anhydride Molded Foam.