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MASTER

MECHANICAL PROPERTIES OF 0.2 g/cm^3 POLYSTYRENE BEAD FOAM

Topical Report

D. J. Fossey, Project Leader

Published January 1978

Prepared for the United States Department of Energy Under Contract Number EY-76-C-04-0613.

Bendix Kansas City Division

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Department 814

Topical Report

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Communications Services Bendix Kansas City Division

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BDX-613-1725 (Rev.), UNCLASSIFIED Topical Report, Published January 1978

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The mechanical properties of 0.2 g/cm^3 polystyrene bead foam, used as an encapsulant of electronic devices, needed to be determined in order that stresses on components could be predicted. The properties were determined as a function of temperature and residual pentane content. A comparison is made of the mechanical properties of potting polystyrene bead foam to structural polystyrene bead foam. The prime difference between the two types of foam is the degree of fusion between the beads obtained during the fusion cycle.

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SUMMARY

In order to better interpret the results from a strain gage investigation of the effects of stress induced by polystyrene bead foam (PSBF) on electronic devices, the tensile and compressive properties of 0.2 g/cm^3 potting PSBF needed to be determined. These data are also required for mathematical models being employed to predict the force PSBF may exert on components. The properties were determined to be a function of temperature and residual pentane (blowing agent) content at -54°, 25°, and 74°C. Both as-molded pentane content (1.4 percent) and heat-aged pentane content (less than 0.2 percent) were evaluated. Five specimens were tested at each condition. The material evaluated was BF-61 expandable polystyrene bead obtained from the BASF Corporation and molded to simulate the foam used for potting electronic components.

DISCUSSION

SCOPE AND PURPOSE

This project was undertaken to measure the force exerted by polystyrene bead foam (PSBF) on electronic components during an encapsulation process. The work includes determination of the mechanical properties of 0.2 g/cm^3 polystyrene bead foam and extensive strain gaging of a functional unit. A comparison to the same effects of polyurethane foam on the electronic components will be made. This report gives only the results of the physical properties investigation.

PRIOR WORK

The mechanical properties of 0.05 g/cm^3 and 0.1 g/cm^3 PSBF have been reported previously.[1] Other work has provided limited data about 0.24 g/cm^3, 0.3 g/cm^3, 0.4 g/cm^3, and 0.5 g/cm^3 PSBF.[2,3] Little data have been reported for 0.2 g/cm^3 PSBF.

ACTIVITY

Test Specimen Preparation

Test specimens (28.68 mm diameter by 25.4 mm high) were used to determine both the tensile and compressive properties. Three, 12-cavity molds (Figure 1) were designed and built. The temperature of each mold during the molding cycle was determined. A thermocouple was placed in the center of one corner and another was placed in the center cavity.

The expandable polystyrene beads were first pre-expanded and then screened using 20 and 30 mesh U.S. Standard screens. The resulting bulk density was 0.2 g/cm^3 with a pentane content of 4.39 percent. With one plate bolted to the mold, the 12 cavities were filled with the pre-epxanded beads. The molds were then vibrated to obtain maximum packing.

After each cavity was topped with additional beads, the second plate was bolted to the mold. The heat cycle used was 35 minutes at 107°C plus an additional 25 minutes at 100°C. This heat cycle reproduces the temperature profile obtained in the center of the encapsulated unit using a 60 minute, 100°C heat cycle. The same degree of bead fusion was obtained in both cases.

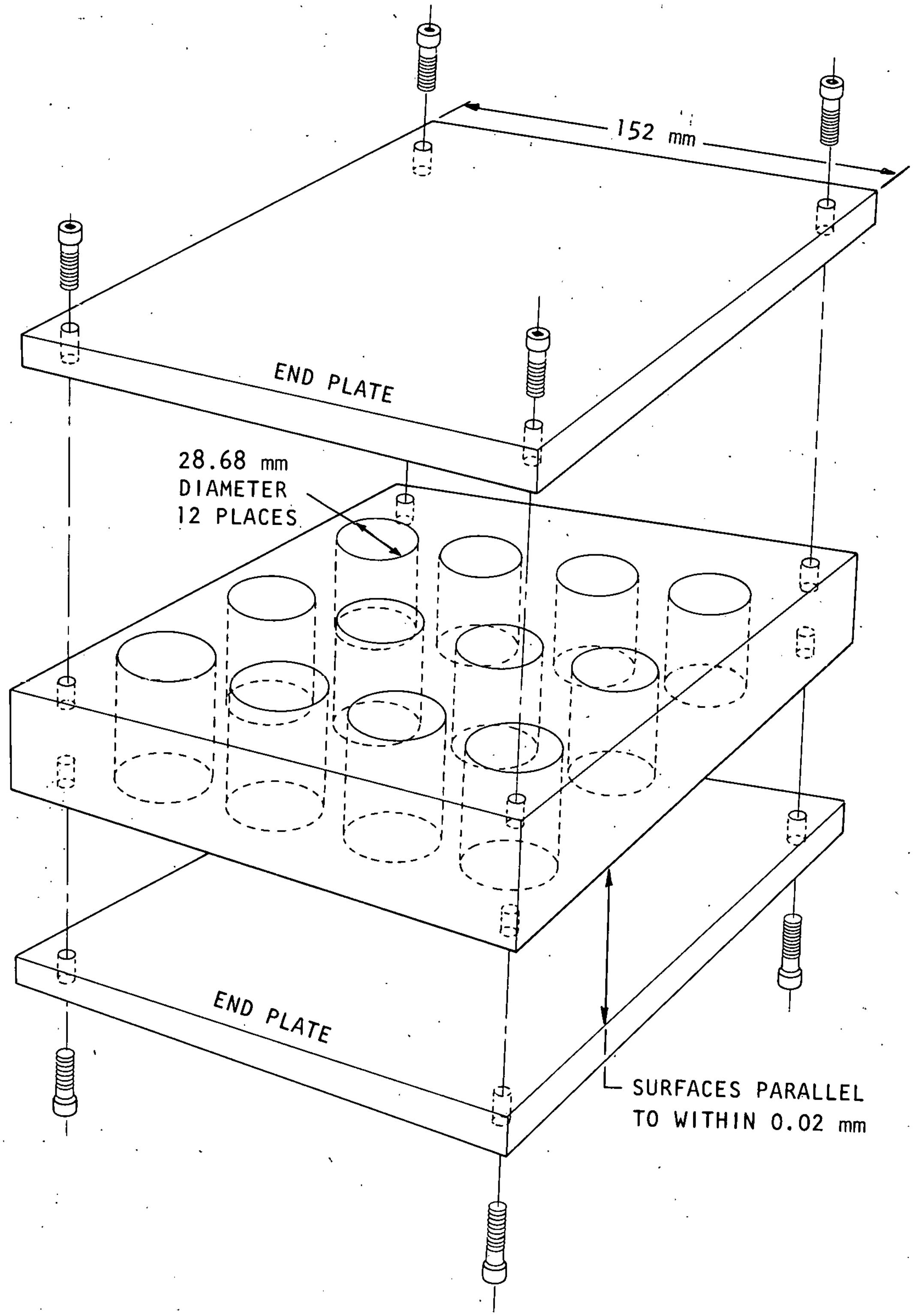

Figure 1. Test Specimen Mold

Seventy-two test specimens were molded and randomly numbered. Each specimen was weighed and measured to calculate density. Fifteen specimens were bonded to aluminum bars using an epoxy adhesive for tensile testing. The adhesive was cured for 2 hours at 71°C. Another 15 specimens were compressive tested. Three additional specimens were tested for pentane content determination at the time of tensile and compressive testing. The as-molded pentane content was determined to be 2.5 percent. The pentane content of the specimens at the time they were tested had dropped to 1.4 percent. Another 37 specimens were placed in an air circulating oven at 71°C for 3 weeks; then, the oven temperature was raised to 77°C. After 2 additional weeks these specimens were removed from the oven and reweighed after 24 hours aging at room temperature. The average weight loss during the heat-aging period was 2.33 percent with a corresponding decrease in volume. There was no change in the density of the specimens. The residual pentane in the specimens, however, was determined to be about 0.2 percent.

Another set of 12 test specimens were also molded using the same lot of pre-expanded beads, but with a heat cycle of 50 minutes at 107°C plus an additional 10 minutes at 100°C. This heat cycle resulted in a higher degree of fusion between the beads resulting in a stronger foam.

Five of these test specimens were bonded to aluminum tensile bars and another five were used for compressive testing. The remaining two specimens were used to determine the pentane content of the foam. The pentane content of as-molded and when-tested specimens was determined to be 1.8 and 1.2 percent respectively. The 12 specimens were tested at ambient temperature only.

Test Results

The reported tensile data for each tensile specimen tested are shown in Table 1 for both the as-molded and heat-aged 0.2 g/cm^3 potting PSBF. Similar data for the compressive tested specimens are given in Table 2. The average values at each test condition were calculated for both the tensile and compressive results (Tables 3 and 4). These average values are shown graphically as a function of temperature in Figure 2 (yield strength), Figure 3 (modulus), and Figure 4 (deflection at yield). The individual test results for the structural PSBF are given in Table 5, with the average values shown in Tables 3 and 4.

The mechanical properties of PSBF are primarily a function of degree of bead fusion, foam density, temperature, and pentane content. The degree of fusion achieved between the individual polystyrene beads during the fusion cycle will vary depending

Text continued on page 14.

Table 1. Tensile Data for 0.2 g/cm^3 Potting PSBF

Test Temperature (°C)	Foam Density (g/cm^3)	Yield kPa (psi)	Modulus MPa (ksi)	Deflection at Yield (Percent)
As-molded PSBF with residual pentane content of 1.4 percent				
-54	0.198	1014 (147)	233.0 (33.8)	0.43
-54	0.206	421 (61)	222.0 (32.2)	0.20
-54	0.209	875 (127)	208.2 (30.2)	0.43
25	0.208	883 (128)	210.3 (30.5)	0.42
25	0.214	1111 (161)	202.7 (29.4)	0.59
25	0.195	586 (85)	179.3 (26.0)	0.40
25	0.196	786 (114)	191.0 (27.7)	0.45
25	0.214	469 (68)	157.9 (22.9)	0.35
74	0.209	903 (131)	119.3 (17.3)	0.78
74	0.216	1179 (171)	170.3 (24.7)	0.79
74	0.210	938 (136)	160.7 (23.3)	0.71
74	0.210	1103 (160)	152.4 (22.1)	0.75
Heat-aged PSBF with residual pentane content of less than 0.2 percent				
-54	0.214	842 (122)	256.5 (37.2)	0.30
-54	0.197	448 (65)	201.3 (29.2)	0.20
-54	0.186	393 (57)	189.6 (27.5)	0.25
-54	0.212	572 (83)	233.1 (33.8)	0.25
-54	0.189	303 (44)	219.3 (31.8)	0.15
25	0.211	510 (74)	155.1 (22.5)	0.30
25	0.202	531 (77)	162.7 (23.6)	0.30
25	0.212	324 (47)	191.7 (27.8)	0.20
25	0.192	462 (67)	160.7 (23.3)	0.30
25	0.208	1027 (149)	200.0 (29.0)	0.50
74	0.214	517 (75)	153.1 (22.2)	0.35
74	0.193	814 (118)	127.6 (18.5)	0.65
74	0.187	538 (78)	102.7 (14.9)	0.50

Crosshead speed of 5 millimeters/minute (0.2 inch/minute)

Table 2. Compressive Data for 0.2 g/cm^3 Potting PSBF

Test Temperature (°C)	Foam Density (g/cm^3)	Yield kPa (psi)	Modulus MPa (ksi)	Strength at 10 Percent Stress kPa (psi)	Deflection at Yield (Percent)
As-molded PSBF with residual pentane content of 1.4 percent					
-54	0.216	4923 (714)	205.5 (29.8)	4914 (712)	4.3
-54	0.192	3530 (512)	151.7 (22.0)	1848 (268)	3.8
-54	0.209	4013 (582)	183.4 (26.6)	2482 (360)	3.3
-54	0.210	4854 (704)	205.5 (29.8)	4680 (679)	4.7
-54	0.200	4296 (623)	183.4 (26.6)	4013 (582)	3.7
25	0.218	2675 (388)	158.6 (23.0)	1482 (215)	2.6
25	0.189	2386 (346)	133.8 (19.4)	1937 (281)	3.5
25	0.216	3123 (453)	166.2 (24.1)	2758 (400)	3.5
25	0.220	3296 (478)	158.6 (23.0)	2986 (433)	3.7
25	0.207	2448 (355)	140.0 (20.3)	1151 (167)	2.6
74	0.205	1675 (243)	140.0 (20.3)	1482 (215)	3.0
74	0.212	1620 (235)	100.0 (14.5)	1103 (160)	2.2
74	0.208	1558 (226)	120.0 (17.4)	1151 (167)	2.5
74	0.222	1944 (282)	145.5 (21.1)	1689 (245)	2.5
74	0.207	1724 (250)	133.8 (19.4)	1613 (234)	2.3
Heat-aged PSBF with residual pentane content of less than 0.2 percent					
-54	0.207	4344 (630)	156.5 (22.7)	3916 (568)	5.0
-54	0.207	2698 (390)	137.9 (20.0)	1379 (200)	2.5
-54	0.207	3972 (576)	137.9 (20.0)	2551 (370)	4.5
-54	0.206	3916 (568)	191.7 (27.8)	2179 (316)	4.0
-54	0.212	4137 (600)	181.3 (26.3)	2068 (300)	4.0

Table 2 Continued. Compressive Data for 0.2 g/cm^3 Potting PSBF

Test Temperature (°C)	Foam Density (g/cm^3)	Yield kPa (psi)	Modulus MPa (ksi)	Strength at 10 Percent Stress kPa (psi)	Deflection at Yield (Percent)
25	0.216	2889 (419)	156.5 (22.7)	*	3.0
25	0.184	2386 (346)	127.6 (18.5)	*	3.5
25	0.192	2813 (408)	132.4 (19.2)	2882 (418)	3.3
25	0.195	2986 (433)	156.5 (22.7)	3130 (454)	3.3
25	0.204	3103 (450)	153.1 (22.2)	2351 (341)	3.3
74	0.188	1786 (259)	115.1 (16.7)	1427 (207)	3.5
74	0.202	2234 (324)	143.4 (20.8)	2158 (313)	4.0
74	0.205	1889 (274)	123.4 (17.9)	979 (142)	3.0
74	0.199	2055 (298)	123.4 (17.9)	1896 (275)	3.3
74	0.212	2262 (328)	128.2 (18.6)	2103 (305)	4.0

*Samples crumbled under load
Crosshead speed of 1.3 millimeters/minute (0.05 inch/minute)

Table 3. Average Tensile Characteristics of 0.2 g/cm^3 PSBF

Test Temperature (°C)	Yield kPa (psi)	Modulus MPa (ksi)	Deflection at Yield (Percent)
-54*	772 (112)	221.3 (32.1)	0.35
25*	765 (111)	188.2 (27.3)	0.44
74*	1034 (150)	150.3 (21.8)	0.76
-54**	510 (74)	220.0 (31.9)	0.23
25**	572 (83)	173.8 (25.2)	0.32
74**	620 (90)	127.6 (18.5)	0.50
25***	1344 (195)	203.4 (29.5)	0.68

*Tested at indicated temperature, as-molded, with residual pentane content of 1.4 percent.
**Tested at indicated temperature, heat-aged, with residual pentane content of 0.2 percent.
***Structural foam tested at indicated temperature, with residual pentane content of 1.2 percent.

Table 4. Average Compressive Characteristics of 0.2 g/cm^3 PSBF

Test Temperature (°C)	Yield kPa (psi)	Stress at 10 Percent Deflection kPa (psi)	Modulus MPa (ksi)	Deflection at Yield (Percent)
-54*	4323 (627)	3585 (520)	186.2 (27.0)	4.0
25*	2786 (404)	2062 (299)	151.7 (22.0)	3.2
74*	1703 (247)	1407 (204)	127.6 (18.5)	2.5
-54**	3806 (552)	2420 (351)	161.3 (23.4)	4.0
25**	2834 (411)	2786 (404)	145.5 (21.1)	3.3
74**	2048 (297)	1710 (248)	126.9 (18.4)	3.6
25***	3192 (463)	3110 (451)	173.1 (25.1)	3.6

*Tested at indicated temperature, as-molded, with residual pentane content of 1.4 percent.
**Tested at indicated temperature, heat-aged, with residual pentane content of 0.2 percent.
***Structural foam tested at indicated temperature, with residual pentane content of 1.2 percent.

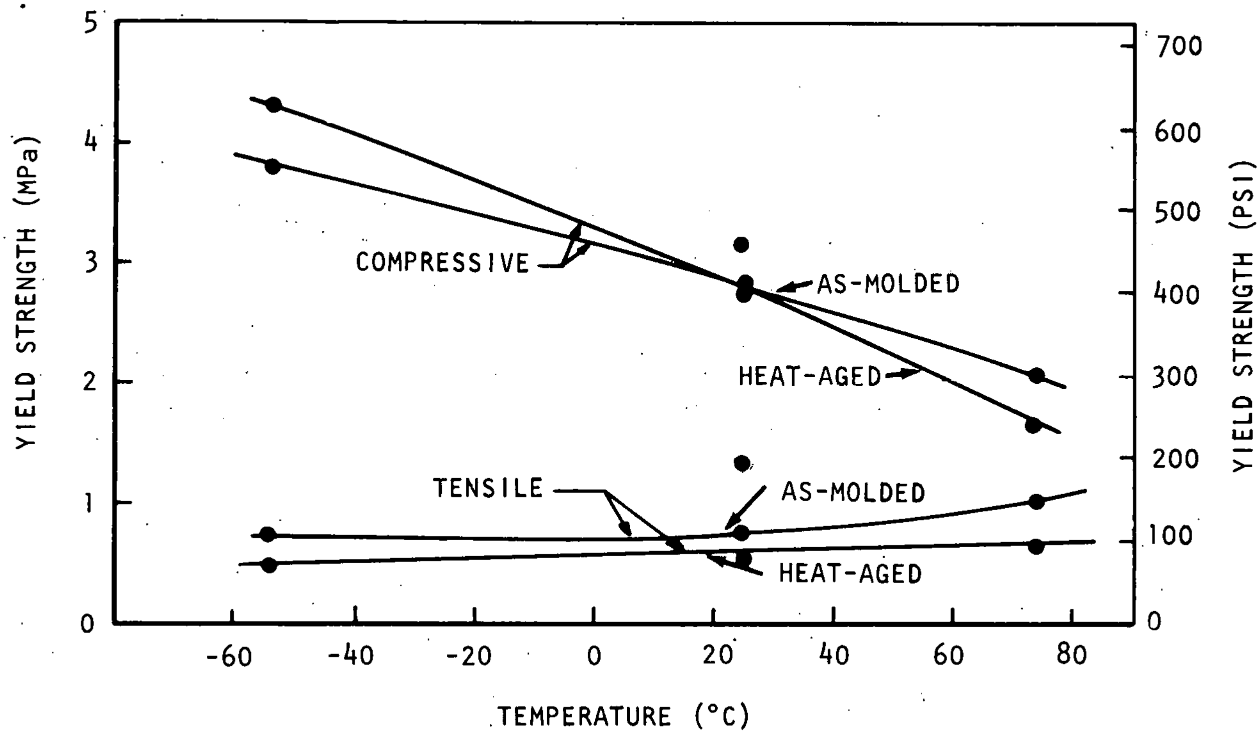

Figure 2. Yield Strength Versus Temperature for 0.2 g/cm^3 Potting PSBF

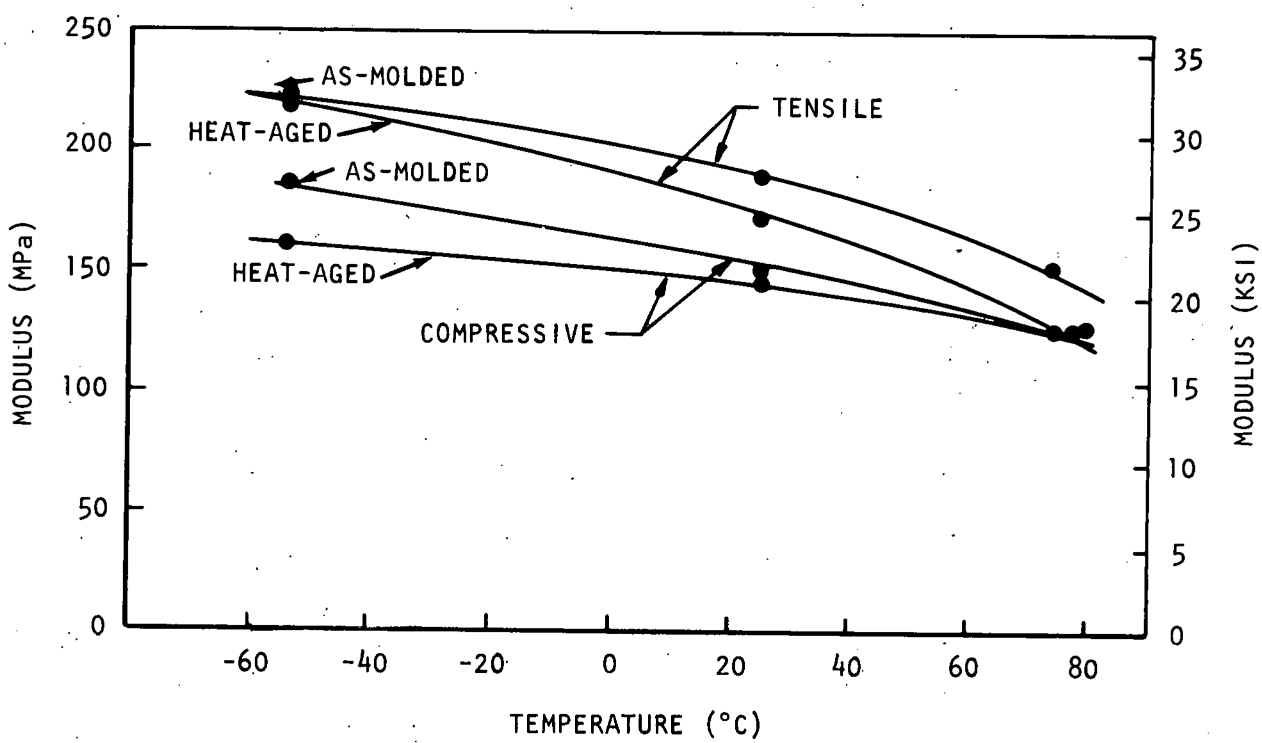

Figure 3. Modulus Versus Temperature for 0.2 g/cm^3 Potting PSBF

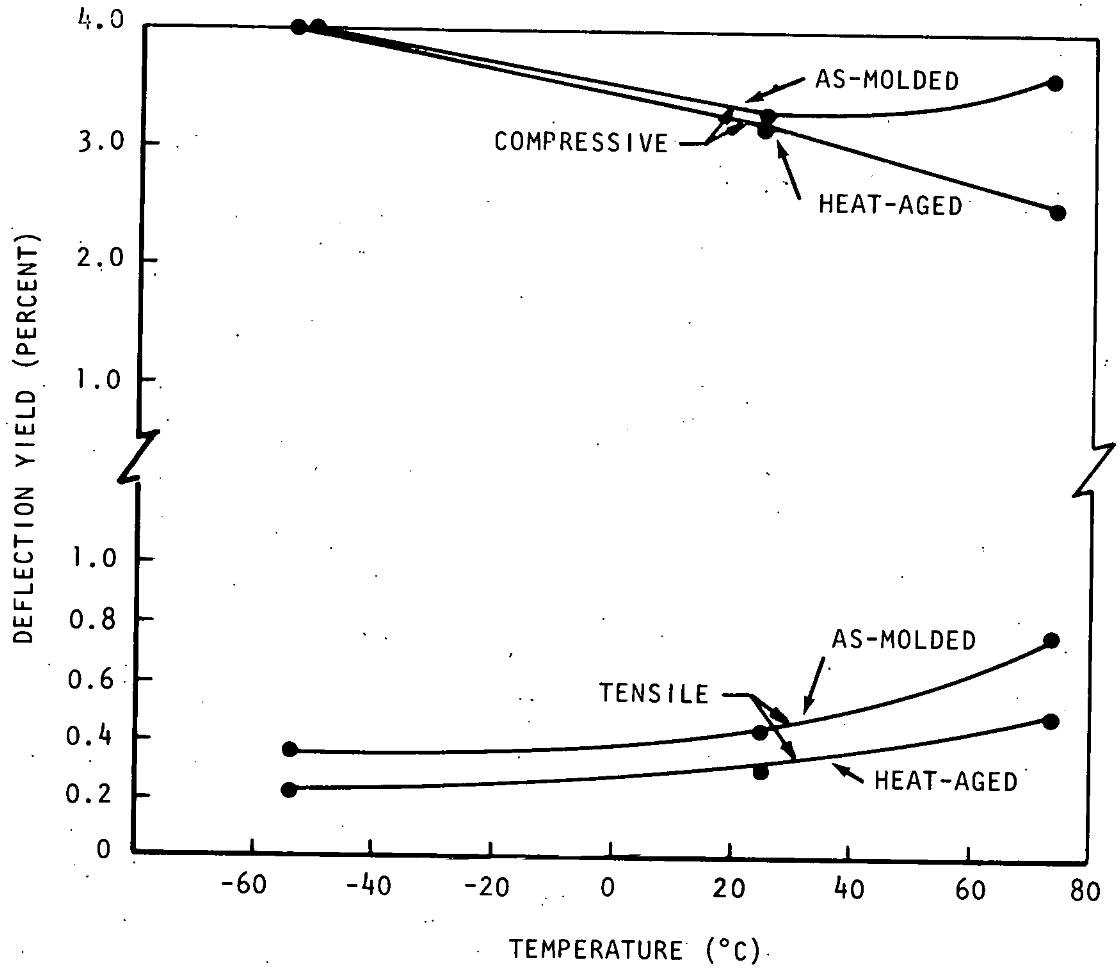

Figure 4. Deflection at Yield Versus Temperature for 0.2 g/cm³ Potting PSBF

on the minimum fusion temperature and length of time the beads are held at fusion temperature. To complicate matters, the minimum fusion temperature varies with the amount of pentane in the polystyrene resin. Previous work indicated there is about a 6°C decrease in the glass transition temperature (Tg) for every 1 percent of pentane in the resin.[1] Pentane in the polystyrene causes the resin to expand once the Tg has been reached as well as softening the resin allowing it to fuse together at a lower temperature. The minimum fusion temperature is considered to be about 10°C above the Tg.

All previous applications of PSBF at Bendix required maximum mechanical strength for a given density. Thus, the beads were fused together at a temperature of about 20°C above the Tg. This resulted in a foam structure in which the beads could not be removed intact from the foam. This type of foam was referred to as structural PSBF.

Table 5. Structural 0.2 g/cm^3 PSBF Tensile and Compressive Data Taken at Ambient Temperature.

Density	Yield kPa (psi)	Modulus MPa (ksi)	Deflection at Yield (Percent)	Stress at 10 Percent Deflection kPa (psi)
Compressive Data*				
0.204	3096 (449)	166.2 (24.1)	4.5	3075 (446)
0.205	3179 (461)	174.4 (25.3)	3.2	3041 (441)
0.208	3261 (473)	183.4 (26.6)	3.5	3185 (459)
0.212	3351 (486)	183.4 (26.6)	3.5	3233 (469)
0.203	3076 (446)	158.6 (23.0)	3.2	3041 (441)
Tensile Data**				
0.204	1179 (171)	174.4 (25.3)	0.69	
0.210	1393 (202)	225.5 (32.7)	0.62	
0.207	1338 (194)	188.9 (27.4)	0.75	
0.210	1393 (202)	215.8 (31.3)	0.78	
0.209	1413 (205)	212.4 (30.8)	0.55	

*Crosshead speed of 1.3 millimeters/minute (0.05 inch/minute)
**Crosshead speed of 5 millimeters/minute (0.2 inch/minute)
Residual pentane content of 1.2 percent.

When PSBF is used as an encapsulant for electrical components it does not require maximum mechanical properties. In fact, it may be a better encapsulant if maximum properties are not obtained. With lower mechanical properties, the PSBF would have less effect on the components and solder joints during thermal cycling. When a fusion temperature of about 10°C above the Tg is used, a foam structure is produced in which the individual beads have not completely lost their identity and can be easily removed from the foam. Usually the beads have not expanded to completely fill the void space around them and are only fused together where they touch. This type of foam was evaluated for this project and referred to as potting PSBF.

Figures 5 and 6 show the mechanical properties of structural PSBF as a function of density over a range of 0.05 g/cm^3 to 0.5 g/cm^3. These two graphs were drawn primarily from previously

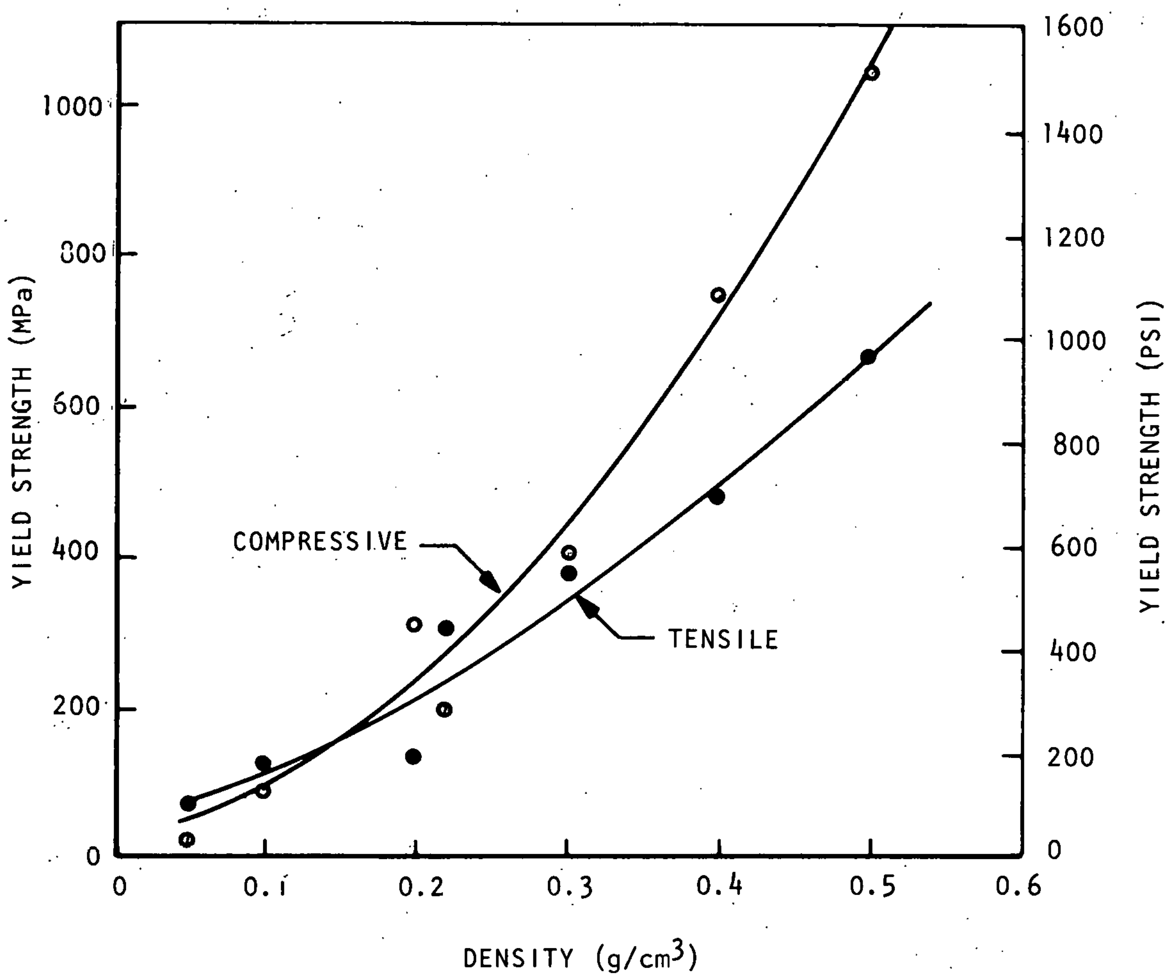

Figure 5. Tensile and Compressive Yield Strengths Versus Density of Structural PSBF

reported data (Table 6). Except for the 0.2 g/cm^3 PSBF, the data are from specimens made from SK 572 expandable polystyrene beads supplied by Arco Polymers Incorporated. The 0.2 g/cm^3 specimens were made from the BASF BF-61 material.

Figure 7 shows the compressive strength of the potting PSBF for densities ranging from 0.19 g/cm^3 to 0.24 g/cm^3. These data were obtained from test specimens, 55 mm in diameter by 25 mm high, molded at the same time units were being encapsulated.

The effect of elevated temperature on the mechanical properties of most polymers lowers the yield strength and increases the elongation with increasing temperature. Residual pentane, acting as a plasticizer, has the same effect as temperature does on polymers; as the amount of residual pentane increases, yield strength decreases, and elongation increases.

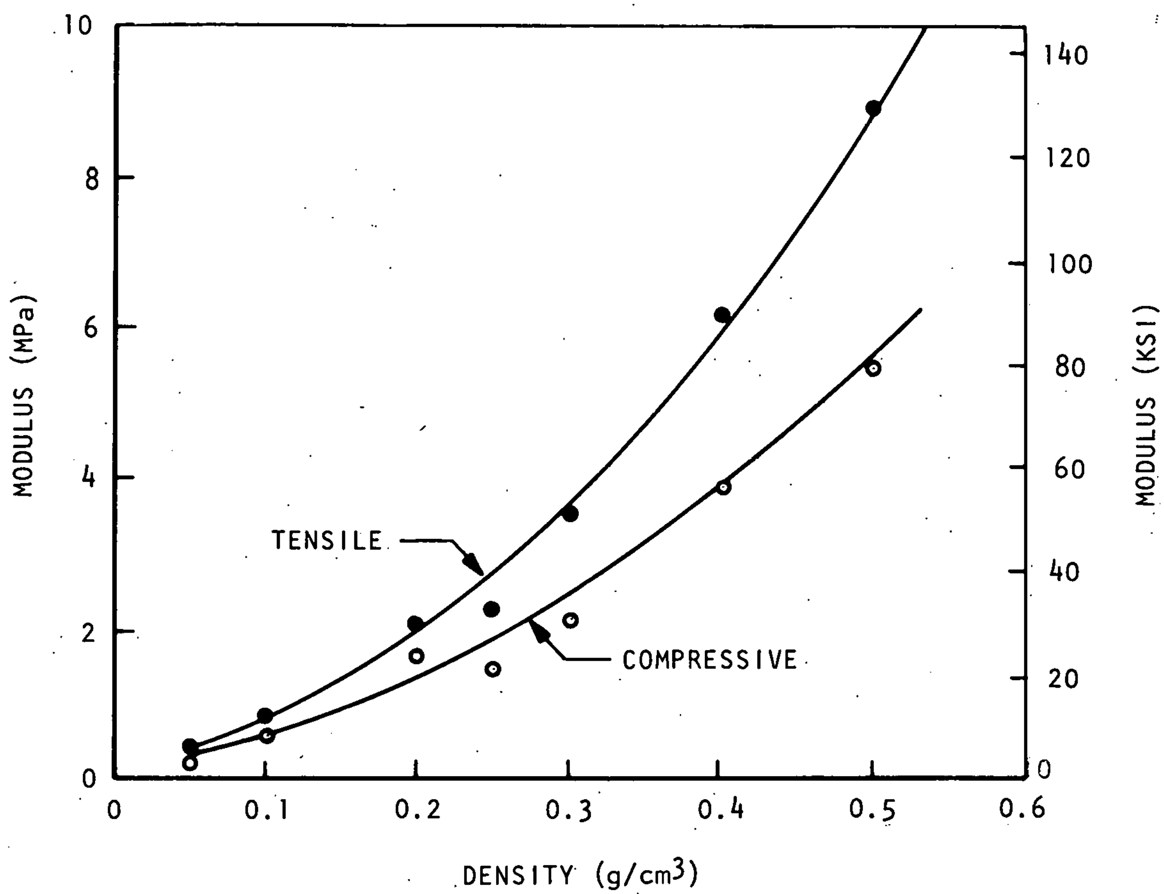

Figure 6. Tensile and Compressive Modulii Versus Density of Structural PSBF

Interpretation of Test Results

The scatter in the potting PSBF data shown in Tables 1 and 2 and Figure 7 can be caused by different degrees of fusion from specimen to specimen. Conversely, the data for the structural PSBF (Table 5) was not as scattered and appeared to be directly related to the differences in the densities of the specimens.

The effect of temperature on the mechanical properties of the potting PSBF was apparent as shown in Figures 2, 3, and 4. As expected, the compressive yield strength for both as-molded and heat-aged specimens decreased with an increase in temperature. The tensile yield strength data, however, showed a slight increase with increasing temperature. This was not expected and was probably caused by a higher degree of fusion achieved on the average in the specimens tested at 77°C.

Table 6. Mechanical Properties of Structural PSBF as a Function of Density

Density (g/cm^3)	Tensile Yield kPa (psi)	Compressive Yield kPa (psi)	Tensile Modulus MPa (ksi)	Compressive Modulus MPa (ksi)
0.05*	690 (100)	345 (50)	41 (6)	34 (5)
0.10*	1241 (180)	1034 (150)	83 (12)	69 (10)
0.20**	1379 (200)	3172 (460)	207 (30)	172 (25)
0.24***	3034 (440)	2068 (300)	228 (33)	152 (22)
0.30†	3792 (550)	4137 (600)	352 (51)	220 (32)
0.40†	4826 (700)	7585 (1100)	621 (90)	400 (58)
0.50†	6688 (970)	10549 (1530)	896 (130)	558 (81)

*Reference 1
**Table 3
***Reference 2
†Reference 3

Figure 4 shows that the deflection (elongation) at tensile yield increased with increasing temperature and the deflection at the compressive yield point decreased with increasing temperature. This unexpected trend may be because the compressive yield strength was about 2.5 times greater at -54°C than it was at 77°C, thereby allowing the PSBF to deflect further before yielding and over-shadowing the plasticizing effect of temperature.

The effect of the amount of residual pentane in the potting PSBF was different than it was for structural PSBF. Structural PSBF (0.05 g/cm^3 and 0.1 g/cm^3) had a 10 percent increase in tensile yield strength for each percent of residual pentane removed. The data reported for the 0.2 g/cm^3 potting PSBF showed about a 20 percent decrease in the tensile yield strength at each test temperature. The effect of heat-aging on the compressive yield strength of the 0.2 g/cm^3 potting PSBF produced a large decrease at -54°C but increased the strength at 77°C, with essentially the same strength at 25°C. Here again, the degree of fusion apparently masked the plasticizing effect of residual pentane in the potting PSBF.

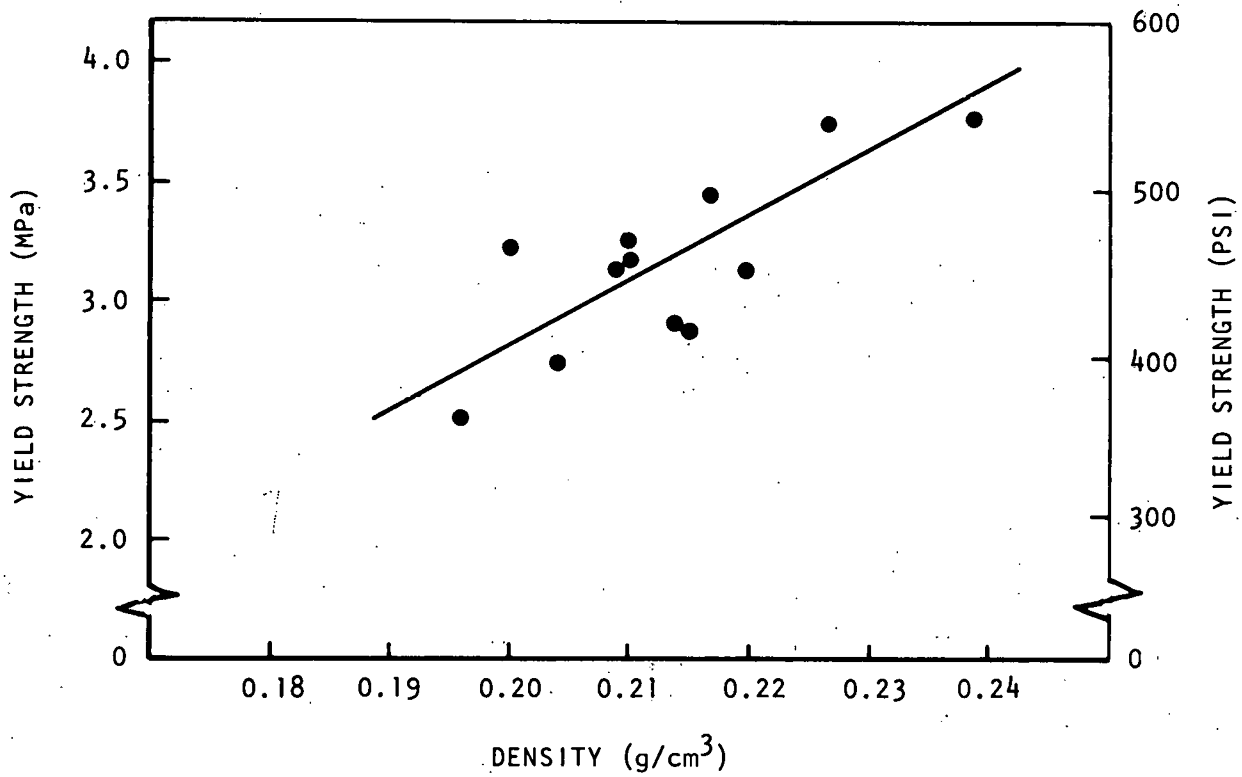

Figure 7. Compressive Yield Strength Versus Density of Potting PSBF

It was also noted that the degree of bead fusion has more effect on the tensile properties of the foam than on the compressive properties as would be expected. A low percentage of poorly fused beads would be more effective in causing a lower tensile strength than they would be in causing a compressive failure. This was also apparent in the large increase in the tensile strength and only a moderate increase in the compressive yield strength in going from the potting PSBF to the structural PSBF.

ACCOMPLISHMENTS

The mechanical properties of 0.2 g/cm^3 potting PSBF were determined to be a function of temperature and residual pentane content. The room temperature tensile and compressive yield strengths were determined to be 690 kPa (100 psi) and 2760 kPa (400 psi), respectively, with corresponding modulii of 186 MPa (27 ksi) and 152 MPa (22 ksi). It was also determined that the degree of fusion achieved between the beads has a greater influence on the tensile yield strength of the foam than it does on the compressive yield strength.

REFERENCES

[1]D. J. Fossey, *Design Manual for Polystyrene Foam, Relating Physical, Mechanical, and Chemical Properties* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1033, February, 1975, Available from NTIS.

[2]R. C. Swoboda, *Feasibility Study of Production of 0.24 g/cm³ - Density Polystyrene Bead Foam* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1298, March, 1975, Available from NTIS.

[3]R. C. Swoboda, *Feasibility Study for Producing High-Density Polystyrene Bead Foam* (Final Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1422, August, 1975, Available from NTIS.

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MECHANICAL PROPERTIES OF 0.2 g/cm^3 POLYSTYRENE BEAD FOAM, D. J. Fossey, UNCLAS Topical, BDX-613-1725 (Rev.), January 1978.

The mechanical properties of 0.2 g/cm^3 polystyrene bead foam, used as an encapsulant of electronic devices, needed to be determined in order that stresses on components could be predicted. The properties were determined as a function of temperature and residual pentane content. A comparison is made of the mechanical properties of potting polystyrene bead foam to structural polystyrene bead foam. The prime difference