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**THEORY IDENTIFICATION FOR
MECHANICAL BEHAVIOR OF POLYSTYRENE BEAD FOAMS**

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Abstract

A series of tension-compression tests with variable test rates and temperatures was conducted on SD 505 polystyrene bead foam of 0.05 and 0.1 g/cm³. Descriptions

are given of the test technique and specimens. A discussion is presented of the applicability of the data for design use and how it might be employed.

Introduction

This report summarizes the test series on polystyrene bead (PSB) foam conducted in 1968 by William St. Lawrence, formerly of W-Division, and Manuel Prado and Richard Cortez, both of Support Division. The test series is part of a long-range study on the basic mechanical behavior of foams. The purpose is to identify the appropriate stress-strain theory and to measure some of the moduli values. The

results are presented in this report with the needs of the design engineer in mind.

Some of the foam specimens were made by the old hot water process, and all were made with the formerly used SD505 raw beads. Therefore, the moduli values reported will not necessarily apply accurately to present day foam made with SD572 raw beads. Both 0.05- and 0.1-g/cm³ density foams were tested.

Theory Identification Technique

A series of experiments was designed to provide a reasonably quick, qualitative look at the theory identification problem. The method chosen was a modification of Dong's method.¹ The idea was to apply a ramp loading and ramp unloading strain history repeated at several strain rates.

¹R. G. Dong, Procedures for Experimental Identification of Appropriate Constitutive Theory for Materials, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-71095 (1968).

Three strain rates were used. Figure 1 shows the input functions, and Fig. 2

Fig. 1. Strain input.

Fig. 2. Expected stress response. (a) Elastic, (b) plastic, (c) viscoelastic, (d) viscoelastic plastic.

shows the stress responses expected for various types of materials. The response of PSB foam should categorize its behavior in this respect.

Tests were performed at -40° , 70° , and 120°F and at strain rates of 4.16×10^{-4} , 2.5×10^{-3} , and 1.25×10^{-1} in./in./min. Up to five specimens were tested at each

test condition. A maximum strain of 1.25% was chosen for compressive tests, based on the strains seen in real application at the time of the test series in 1968. The maximum strain was lowered to 0.625% for the tension experiments because premature failure was occurring near the end caps.

Experimental Technique

Material Procurement

The polystyrene bead foam used in this program was obtained through Paula Naillon of W-Division. The 0.1 g/cm^3 density foam was from Bendix, Kansas

City, Missouri, and the 0.05 g/cm^3 density foam was partly from Bendix and partly from Monsanto, Dayton, Ohio. Bendix used the hot water process, while Monsanto used the hot air process.

Specimen Configuration

The specimens were right circular cylinders (Fig. 3) 6 in. long and 2.11 in. in diameter. Aluminum end caps were

bonded on both ends with resinbond 907 using an alignment fixture. (Specimen and fixture are shown in Appendix B.)

Fig. 3. Specimen in test fixture.

Specimen Fabrication

All specimens were machined and inspected at Bendix according to our specifications, and were packaged in desiccated plastic bags. All specimens were made between early December, 1967 and late January, 1968.

When the specimens were received, the average density of each was measured (see Engineering Test Section, Physical Measurements Laboratory, Support Engineering Division, Engineering Test Numbers 6987, 6991, 7015, 7033, and 7070.) The aluminum end caps were then attached.

Desiccating Process

Since the effects of moisture on mechanical behavior of PSB foams are not entirely known, the specimens were kept in desiccated containers at all times. Desiccant boxes were built to contain the alignment fixtures so that the specimens were desiccated during end-capping.

Test Fixture

To minimize the bending during load applications, the end caps were precisely aligned during gluing, and the special test fixture shown in Fig. 3 was used. The loading column is guided by roller bearings to prevent tilting and side sway. The apparatus was used with Support Division's 20,000-lb Instron universal tester.

Test System and Instrumentation

Figures 3, 4, and 5 show the test set-up. The system consisted of the Instron universal tester, its control unit, and the special test fixture which is mounted in the tester. Three extensometers controlled the strain input, and three extensometers and a load cell gave data output on two x,y plotters. A temperature chamber was used.

A Dymec system was later added to extend the data-collecting capability. A transverse strain gage was developed and added in July 1968 to measure the Poisson's ratio.

Summary of Results

Conclusions

The data were quite repeatable, although large variability occurred under some conditions. Both 0.05- and 0.1-density foams exhibited no rate or temperature dependence, at least not within the spread of the data up through 0.004 strain. The foams were nonlinear over their entire response. A linear approximation is, however, acceptable for strains smaller than 0.004 in./in. for both densities. It is interesting that the linear range in terms of strain is the same for both densities. In fact, strain generally

governs the behavior more strongly than stress. Specifically, the shapes of the stress-strain curves are the same, with the curve for 0.1 density roughly twice that for 0.05 density. This implies that bench marks such as the linear limit, yield point, and degrees of crushing are the same when expressed in terms of strain. Strain, therefore, appears to unify the description for many of the mechanical properties.

Linear temperature-independent elasticity is adequate for analysis in which strains remain below 0.004 in./in. Beyond

Fig. 4. Instron tester with controller and temperature chamber.

Fig. 5. Instron tester with analog-to-digital converter and recorder.

this crushing and rate dependency begins, and linear elasticity becomes progressively more inaccurate.

Qualifications

A satisfactory extensometer did not exist at the time of these tests. Strains were based on end displacements rather than being measured over a gage length. Therefore, the results are in error to 3% or less. The data were left uncorrected because the precise amount of corrections was unknown and the batch-to-batch variability far exceeded 3% at that time. Hence, our results must be taken to be no more than approximations to the properties of present day foams.

Application to Analysis

In spite of the qualifications, the data can be used for rough preliminary design

analysis. For this purpose, linear temperature-independent elasticity is acceptable. Its accuracy, of course, diminishes beyond 0.004 strain.

Two properties are needed for linear isotropic analysis, Young's modulus and Poisson's ratio. Our results are presented such that both can be extracted. Stress-strain curves are given in Appendix A, with average curves given in Figs. 6 through 9. The Poisson's ratio versus strain curves are given in Figs. 10 and 11. The fact that linear elasticity is only approximate is now clearly evident. The stress-strain curves are nonlinear, and the lateral-to-longitudinal strain ratio is path-dependent, usually ending at a lower value than at the start. A true Poisson's ratio cannot be assigned; however, a value of 0.30, in our

Fig. 6. Composite of average compression curves. Density = 0.10 g/cm³.

Fig. 7. Composite of average tension curves. Density = 0.10 g/cm³.

Fig. 8. Composite of average compression curves. Density = 0.05 g/cm^3 .

judgment, can be used for rough analysis. The values of Young's modulus to use depends on the strain range of interest. Hence, the first step is to estimate, or guess, the strain of interest. Young's modulus is then extracted from the appropriate average curve of Figs. 6 through 9 as the secant modulus; i.e., the slope of the line from the origin to the point on the curve at this strain. Analysis is carried out and the strains are calculated. The

Fig. 9. Composite of average tension curves. Density = 0.05 g/cm^3 .

strains from the analysis are compared with the estimated value. If they are sufficiently different from the estimated, then the process must be repeated, using the strains from the analysis to extract an improved value of Young's modulus. This iterative process continues until the desired convergence is reached.

Fig. 10. Poisson's ratio versus strain for compression—SD 505 foam. (a) Temperature = -40°F ; density = 0.1 g/cm^3 . (b) Temperature = 70°F ; density = 0.05 g/cm^3 . (c) Temperature = -40°F ; density = 0.05 g/cm^3 . (d) Temperature = 70°F ; density = 0.1 g/cm^3 . (e) Temperature = 120°F ; density = 0.1 g/cm^3 .

Fig. 11. Poisson's ratio versus strain for tension—SD 505 foam. (a) Temperature = -40°F ; density = 0.05 g/cm^3 . (b) Temperature = -40°F ; density = 0.1 g/cm^3 . (c) Temperature = 120°F ; density = 0.1 g/cm^3 .

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Appendix A. Stress-Strain Curves for PSB Foam SD 505

Fig. A-1. Compression stress-strain curves. Rate = 0.000416 in./in./min.

Fig. A-2. Compression stress-strain curves. Density = 0.05 g/cm³.

Density = 0.10 g/cm^3

Fig. A-3. Compression stress-strain curves. Density = 0.10 g/cm^3 .

Fig. A-4. Tension stress-strain curves. Density = 0.05 g/cm³.

Fig. A-5. Tension stress-strain curves. Density = 0.10 g/cm³.

Fig. A-6. Tension stress vs strain.

Appendix B. Foam Specimen and Bonding Fixture Drawings

NOTES:

1. $\frac{1}{2}$ F.A.O.
2. TAG PART NO.
3. ALL SURFACES TO BE FREE OF FOAM DUST.
4. RECORD BLANK SERIAL NO. ON INSPECTION SHEET.
5. PARTS TO BE SEALED IN BAGS WITH DESKIN.

Fig. B-1. Foam specimen (AAA67-122281-OA).

Fig. B-2. Bonding fixture assembly (AAA67-123754-OO).

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