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PRELIMINARY CHARACTERIZATION OF MATERIAL PROPERTIES OF HYDROXYL-TERMINATED POLYBUTADIENE (HTPB) SOLID PROPELLANT

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ABSTRACT

Hydroxy-terminated Polybutadiene, HTPB, which is a fuel used in solid and hybrid rockets is a polymer with unknown mechanical properties. As simulations of rocket motors are undertaken to determine design specifications, it becomes important to know the mechanical properties. Specimens are prepared according to American Society for Testing and Materials (ASTM) specification number D412-98a, D638-02a, and D3182. These specimens are pulled to failure in a standard Instron testing machine. The elastic modulus and yield strength over a number of samples and batches are measured and averaged. The values determined from testing are 1.49 MPa for elastic modulus and 0.57 MPa for tensile strength.

INTRODUCTION

The University of Arkansas at Little Rock has been engaged in hybrid rocket research for a number of years.[1] Much of the work has been experimental and has focused on measurement of plume parameters. However, an increasing emphasis is being placed on simulation. The goal of the simulation is to compare with existing results and to predict future outcomes. In order to make valid simulations, estimates of the material properties for the various substances must be known. Many of the rocket components have well documented properties, such as steel, phenolic, and graphite. However, the fuel properties have not been measured or published.

One fuel used extensively in both solid and hybrid rockets is the polymer, Hydroxl-terminated polybutadiene (HTPB). Mechanically, HTPB behaves as an elastomer. Experiments show that it has a non-Hookean (anelastic) stress-strain relationship. In other words, its relationship between applied stress and resulting strain has no well defined elastic region (characterized by the elastic modulus) or plastic region (characterized by the yield strength and the tensile strength).

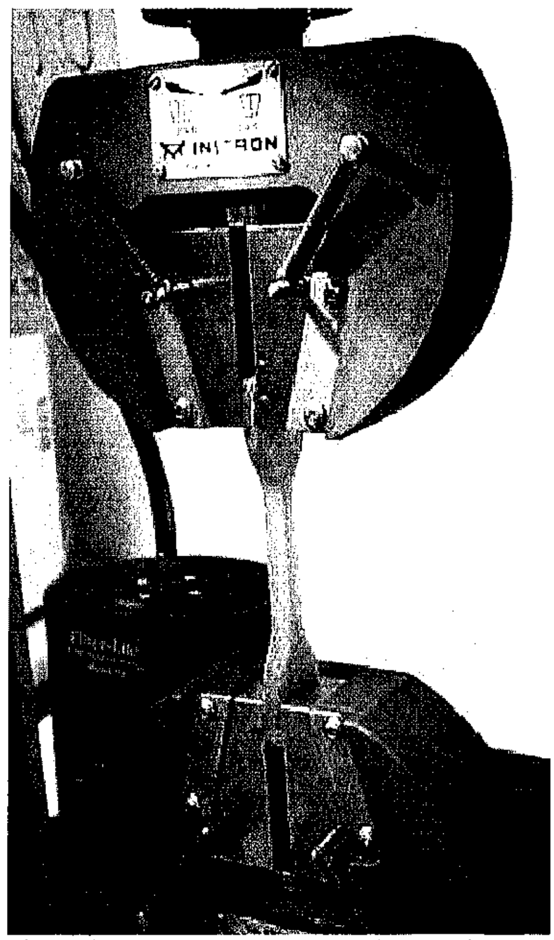

Figure 1- *Instron Testing Grips with HTPB Specimen*

Methods for extracting useful information about elastomeric materials are presented in two ASTM specifications. ASTM standard D412-98a indicates how to determine properties of rubbers, such as tensile set and tensile strength.[2] It does not present a method for measuring the elastic modulus. ASTM standard D 638-02a presents comprehensive methods for determining both elastic modulus and tensile strength for elastomers which exhibit both Hookean and non-Hookean behavior.[3] Although the elastic

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modulus may be a fictitious quantity for an elastomer,[4] Elastic modulus, as determined by D 638-02a, is measured for many elastomers for industrial purposes. ¶

The results reported here indicate that HTPB performs linearly from the point where the load is initially imposed up to the point of failure. Since the load is applied at relatively high strain rate, the viscoplastic term in the linear Kelvin model should be negligible. Further study needs to be done with varying strain rates to verify this.

MANUFACTURE OF HTPB TEST SPECIMEN

The HTPB is prepared according to a procedure which has been developed at UALR[5]. This procedure is summarized as follows.

A quantity of R45 HTPB resin (85%, by weight) is poured into the mixing bowl of a Hobart mixer. A quantity of N100 di-isocyanate (15%, by weight) is added along with a couple of drops of tin-based catalyst. The mixture is stirred and may be degassed using a vacuum system. The mixture is poured into a 381 mm x 76.2 mm rectangular mold. The mold is placed into a 60 °C curing oven for approximately 16 hours. This casting procedure adheres to ASTM Standard D 3182-89.[6]

If other materials are desired in the mixture, such as an opacifier or perhaps a metal to simulate component failures, these materials can be added at the mixing stage in appropriate amounts for the desired effect.[1,7,8,9]

Once the sheet has cured, test specimens are stamped from the sheet using a cutter, which is made per ASTM Standard D 3183-84.[10] Although the standard allows for a variety of different geometries, the dumbbell specimen geometry was chosen, primarily because it was compatible with the grips of UALR's Instron testing machine (see Fig. 1).

A CAD model for the cutter was developed (see Fig. 2), and the cutter was manufactured using UALR's CNC milling machine. Specimens were stamped out using a hand stamp and ejected with pneumatic pressure. The thickness of the specimens was measured at three separate points in the gage section using a micrometer. Specimens which did not adhere to 4.25 mm ± 0.20mm were discarded.

EXPERIMENTAL PROCEDURE

Tests were performed using an Instron Series 5500 Testing System. The elongation rate was set to 500 mm/min and the data acquisition rate was set to 50 ms. All tests were conducted at room temperature. Specimens were stretched to failure.

A strain gage based load cell measured the force applied to the samples. A strain gauge extensometer (Fig 3) measured the extension of two points on the sample. Modified grips were designed to apply uniform pressure across top and bottom of the gage section. These grips eliminated slippage of the extensometer and insured that failure of the specimen occurred in the gage section. This extensometer has a 25.4 mm gauge length and 12.7 mm travel

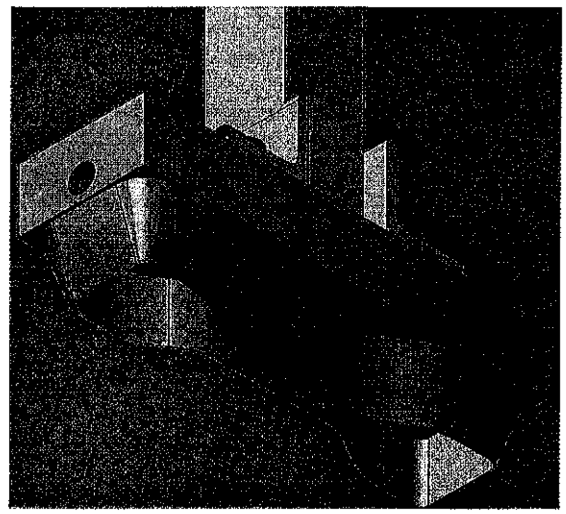

Figure 2- *CAD Model of Dumbbell Cutter*

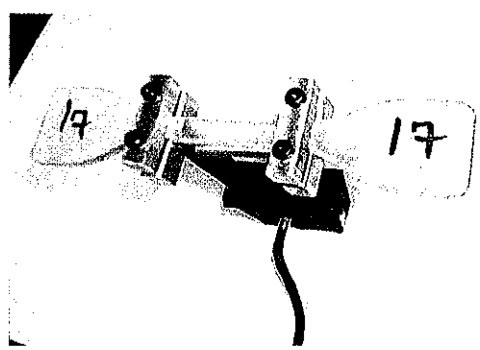

Figure 3- ***HTPB Specimen and Extensometer***

¶ For instance, eFunda (www.efunda.com) P. O. Box 64400, Sunnyvale, CA 94088 regarding how ABS material properties were determined.

RESULTS AND DISCUSSION

Although dozens of samples were tested, many of these samples did not yield consistent results, primarily because the extensometer grips slipped. Experimental techniques were refined until consistent results were achieved. As of the writing of this paper, only 12 good data samples were obtained (see Table 1 and Fig. 5). However, even the samples which were discarded showed values which were consistent with the results presented in this paper.

The initial section on the data (see Fig. 5) shows that extension occurs at zero load. This is the system taking out the slack in the extensometer and was deleted in the determination of strain. Elastic Modulus was calculated as the average slope between 5% and 35% strain. Ultimate tensile strength was determined as the stress value at the point where failure occurred.

CONCLUSIONS

Preliminary values for the elastic modulus, E, and the tensile strength, σ_t, were measured for HTPB. Once the experimental procedure was refined, repeatable stress-strain data was obtained. Further experiments will serve to reduce the variation in these parameters.

The behavior of HTPB is confirmed to be anelastic. The material behaves linearly up to failure. Failure occurs by rupture at maximum load.

Future work will be undertaken to achieve additional good samples, until statistically significant results are obtained. Additional parameters, such as creep, tensile set, specific heat, and speed of sound will be measured. Since rubber is known to change mechanical behavior with temperature, experiments at varying temperatures will be undertaken for completeness.

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Test	Elastic Modulus (MPa)	Tensile Strength (MPa)
1	1.53	0.59
2	1.46	0.54
3	1.55	0.60
4	1.47	0.54
5	1.45	0.56
6	1.44	0.56
7	1.55	0.56
8	1.48	0.59
9	1.39	0.52
10	1.68	0.64
11	1.39	0.54
12	1.45	0.57
Avg	1.49	0.57

Table 1. Summary of Measured Values

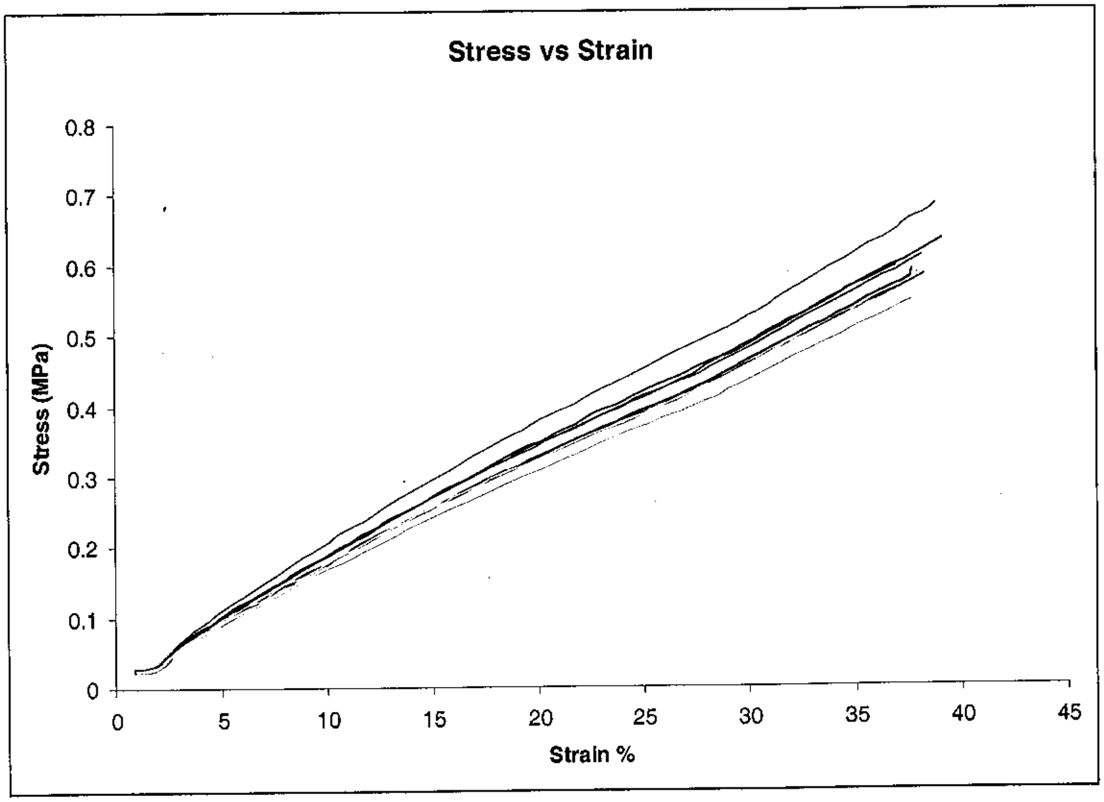

Figure 5 - *Stress vs. Strain of 12 HTPB fuel samples (Deformation rate: 500 mm/min)*