Investigating the Dynamic Mechanical Properties of Polymers Used in Energetic Materials

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I. Introduction

Current energetic materials consist of reactive mixtures encased in steel, which acts as an inert container, but which can account for up to 60% of the total weight. On the other hand, due to lack of strength, the mixtures cannot be used for this purpose. If energetic materials possess structural integrity, then they can substitute for the casing while also producing energy. Polymers are envisioned to be used with reactive mixtures to make structural energetic materials. Due to the high strain rate nature of such applications, Taylor tests are used to study the deformation process under conditions of dynamic loading,[1] in which a cylindrical projectile is accelerated in a gas gun and launched at a hardened steel anvil, and the resulting deformation is studied.

In Taylor's original analysis,[1] a simple rigid-plastic model is used, which cannot be applied to polymers. Hutchings subsequently modified the theory, using an elastic-plastic wave model.[2] Using this method, a yield stress independent of projectile velocity can be calculated and incorporated into stress-strain data to obtain the dynamic response.

II. Procedure

Polymers including nylon 6,6; polytetrafluoroethylene (Teflon); polycarbonate; and polyamide-imide (Torlon) were machined into samples of approximately 0.3-inch diameter and 2-inch length. The samples were loaded into a .30-caliber gas gun and launched at a steel anvil. Laser beam interruption was used to measure the velocity, and strain was calculated from initial and final dimensions of the impacted sample. Strain-velocity data were plotted for each material to find the critical velocity, the velocity at which there is measurable permanent strain. Following Hutchings' technique, numerical methods were used to find the yield stress and strain from the following equations:[2]

$$(Y/\rho V^2)^{1/2} = \overline{C}_p/(\varepsilon_y - \varepsilon_y^2)^{1/2}[1/(1-\varepsilon) - (1-\overline{C}_p)/(1-\varepsilon_y)]$$

$$\varepsilon_y = \frac{\rho V_c^2/Y}{1+(\rho V_c^2/Y)}$$

where Y is yield stress, ρ is density, V is velocity, V_c is critical velocity, ε is strain, ε_y is yield strain, and $\overline{C}_p$ is the ratio of velocities of the plastic and elastic waves. Combined with data from each experiment, stress-strain curves were obtained for each material describing the high strain rate response.

III. Results and Discussion

The strain-velocity curves are shown in Fig. 1, with extrapolation to show the critical velocities.

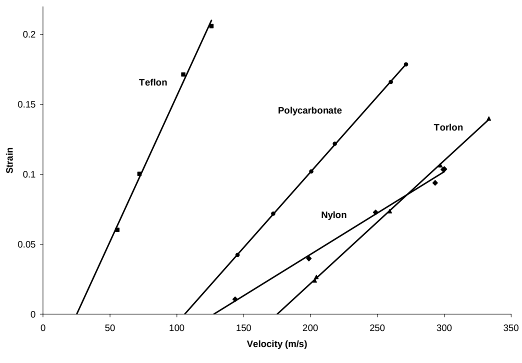

Fig. 1. Strain-velocity curves.

Hutchings' equations[2] were used together with numerical methods to compute yield stress and yield strain (Table 1):

Table 1. Critical velocity and yield data for each material.

	Critical velocity	Yield stress	Yield strain
Nylon	127.71 m/s	379.03 MPa	0.0479
Teflon	25.22 m/s	40.89 MPa	0.0323
Polycarb	105.94 m/s	175.19 MPa	0.0761
Torlon	175.16 m/s	408.25 MPa	0.1061

Torlon has the highest critical velocity, yield stress and yield strain, to be expected since it is a material with high mechanical resistance properties. Combining the yield values with stress and strain data from each experiment produces the stress-strain curves in Fig. 2, which clearly shows the elastic and plastic regions.

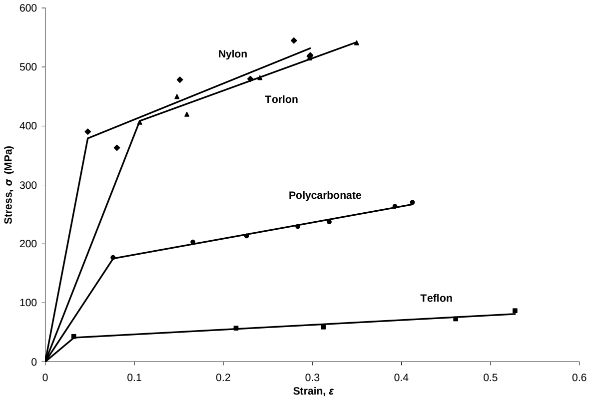

Fig. 2. Stress-strain curves.

The area under the elastic region in Fig. 2 represents the elastic resilience of the material. Based on this data, Torlon exhibited the highest elastic resilience with a value of 21.66 MPa, while the calculated values for nylon, Teflon, and polycarbonate are 9.07, 0.66, and 6.67 MPa, respectively.

IV. Conclusions

Using strain and velocity data from Taylor tests, the dynamic properties of various polymers were studied, allowing for comparison of a range of materials. These mechanical properties contribute to an understanding of both the structural strength and the ability to decompose in order to react with the reactive mixtures, properties that are to be taken into account in the design of structural energetic materials.

V. Acknowledgements

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VI. References

1. Taylor, G. I. (1948). The Use of Flat-Ended Projectiles for Determining Dynamic Yield Stress: I. Theoretical Considerations. *Proc. R. Soc. Lond. A* **194**: 289-299.
2. Hutchings, I. M. (1979). Estimation of Yield Stress in Polymers at High Strain Rates Using G. I. Taylor's Impact Technique. *J. Mech. Phys. Solids* **26**: 289-301.