Technical Notes

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A Novel Smokeless, Nonflaking Solid Propellant Inhibitor

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Introduction

A SMOKELESS inhibitor with a burning rate that matches the burning rate of the propellant has been developed. The most immediate application of this inhibitor is in strand experiments in pressure bombs where smoking and flaking are undesirable. Strand experiments using a servopositioner are difficult to perform without a suitable inhibitor.[1] If the inhibitor burns too rapidly, the strand profile will convert to a cone and most of the surface will be below the correct height. In particular, in photographic experiments most of the surface will be out of focus. If it burns too slowly and leaves large flakes in its residue, it will interfere with the servo-positioning beam. If it smokes, the smoke will tend to mask both the servo-beam and any optics that may be used in the experiment.

The need for a chemical inhibitor first arose in our laboratory during work on propellant deflagration cinephotography.[2] While working with the solid rocket propellant, it became obvious that the propellant has a natural tendency to burn along all free surfaces; consequently, a strand forms a pointed surface during deflagration. Because of the limits in the photographic equipment, the desired burning surface for the experiments was a completely flat plane[2] and parallel to the camera lens, but at an angle with respect to the length of the strand. Unfortunately, untreated propellant will immediately burn on all freely exposed surfaces. This is referred to as "flashing." Flashing produces a pointed surface, unsuitable for our experiments. The relative effectiveness of a number of traditional inhibitors was studied. One common method of inhibition currently being used in strand experiments is simply to leach the propellant with water. If done directly before deflagration, the water does inhibit to a relatively high degree burning down the sides of the strand. However, if the water is applied more than a few minutes before deflagration, its inhibitive properties are reduced greatly. Therefore, it would not be applicable to any experiments where the propellant needs to be prepared long before deflagration is initiated. Also, water does not have the capability of forcing the propellant to burn at a specific angle due to different coating thickness on different sides of the propellant. Silicone grease did not fully prevent the sides from burning and, also, released considerable smoke. The thickness of application of the grease did not affect its performance. Sodium silicate left too much residue or char; and a number of other commonly available materials, including lacquer and teflon, were tested with unsatisfactory results (see Fig. 1).

Experiments

Testing of alternative inhibitors has shown that a phenol formaldehyde polymer works very well as an inhibitor on propellant strands, provided that it is properly prepared with an appropriate solvent. This phenol-formaldehyde polymer is in a partially reacted, thermoplastic state (Fig. 2). It is applied to all free surfaces of the solid rocket propellant, excluding the desired burning surface. The polymer will prevent the deflagration process from spreading to all free surfaces on the propellant, in order to achieve greater control over the burning propellant. If the concentration of the inhibitor layer is correct and the inhibitor thickness is in an appropriate range, the polymer will also burn away at the same rate as the propellant. In this case, there is no shell formation or intrusive residue left behind.

Once the polymer was established as having the most promising performance, further tests were performed to optimize the application procedure. The optimum concentration for the inhibitor coating of phenol in acetone depends on the operating pressure. An example of results for low-pressure operation is shown in Fig. 3. It is expected that the optimum concentration will be different for propellants of varying formulations. Experiments were also undertaken to find the most appropriate solvent; acetone yielded a product with the most consistent results. Tests with 1000 weight polyethelene glycol (PEG) as an additive showed that more than 0.2 g/ml of PEG added to the phenolic solution will cause flaking.

The initial results obtained with this inhibitor are very encouraging, but further work is needed to obtain a no-smoke/no-flake product of general interest in the solid-propellant combustion community. Additives are needed to increase the burning rate to match high-regression-rate conditions. Work should also be done to improve quality control, which is primarily limited by long (6 h) drying times. Quality control could be improved with oven drying, and both conventional and microwave ovens are possibilities for this process. A vat should be designed to control the length of the coating application time. This quality assurance would aid the progress of both research-level strand experiments and any widespread use in the solid propellant community. Additives are needed to increase the flexibility of the coating. Possible

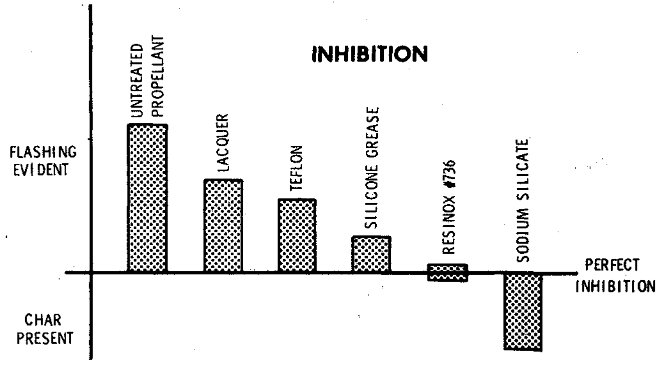

Fig. 1 Qualitative performance of commonly used inhibitors for strand experiments.

Received Oct. 8, 1985; revision received Nov. 29, 1985.

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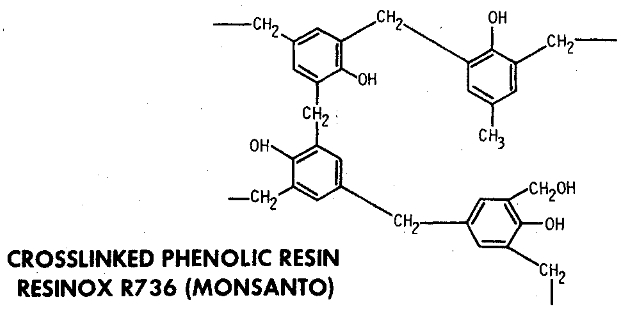

Fig. 2 Chemical structure of phenolic resin copolymer unit.

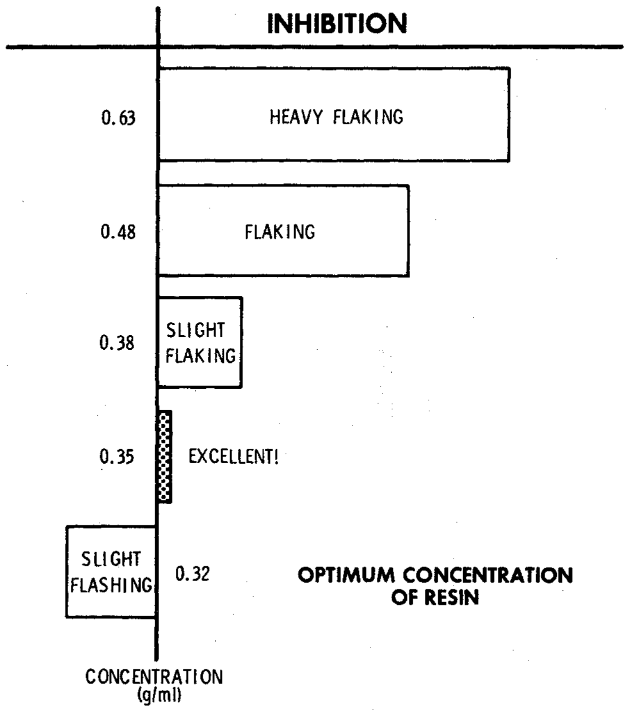

Fig. 3 Qualitative behavior of polymer inhibitor vs solution concentration.

agents for enhancing flexibility are clean-burning cellulose fibers or various rubber-based compounds. The present formulation was developed for work at low (50-200 psi) pressures. Formulations for work at higher (300-1000 psi) pressures can easily be developed.

Acknowledgments

The authors are thankful to Dr. Ival Salyer for suggesting the use of the phenolic resin and for much helpful advice during the course of our experiments. This work was supported by the Air Force Rocket Propulsion Laboratory under Contract F04611-83-1L-0023.

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[2]Becker, R. J. and Laird, J. L., "Optical Considerations in Obtaining a Statistical Data Base on Propellant Deflagration," Presented at JANNAF Fall Meeting on Combustion, Pasadena, CA, Oct. 1985.

Gradual Opening of Skewed Passages in Wave Rotors

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Introduction

THE problem of gradual opening of rectangular axial passages in wave rotors was studied in Ref. 1. In that reference, the mathematical model used to simulate the opening process was decribed in detail. This Note is intended as an extention of the previous article.

Historically, most wave machines designed to produce shaft power had skewed passage.[2,3] For this reason opening of a skewed passage is analyzed in this paper, and conclusions drawn for the case of rectangular axial passages are examined in light of the results for the skewed case.

Results and Discussion

The main conclusion of the study on the gradual opening of the rectangular passage is that in order to minimize the mixing losses caused by rotational flow in the passage, opening of the wave rotor passage will lead to a one dimensional flow pattern in the passage which will in turn lead to minimal mixing losses.

When the passage of the wave rotor is skewed, even an instantaneous opening of the passage will not lead to the development of a one dimensional flow pattern with small losses.

As an example, the opening process for a passage 0.02 m wide and 0.24 m long is modeled. The passage has left and right hand inlets parallel to the Y axis and the upper and lower wall of the passage form a 60 deg angle with the positive direction X axis. It is assumed that initially air in the passage is at the following conditions:

$$P_0 = 1 \text{ atm}; \quad \rho_0 = 1.2 \text{ kg/m}^3; \quad U_0 = 0; \quad V_0 = 0$$

The driver gas entering through the port at the left hand end is assumed to having the following properties:

$$P_d = 1.8 \text{ atm}; \ \rho_d = 1.81 \text{ kg/m}^3; \ U_d = 75 \text{ m/s}; \ V_d = 129.9 \text{ m/s}$$

The conditions for the driver and driven gas are the same as those assumed for the case of the rectangular passage as reported in the Ref. 1.

Figures 1a and b illustrate results obtained from the simulation of the instantaneous opening of the skewed passage in the form of pressure and velocity contours at a sequence of times. The flow pattern near the inlet in Fig. 1 is highly rotational which suggests very high mixing losses. This pattern arises partially because of the reorientation of the shock wave. In the first moments following the opening of the passage, the shock wave between the driven and driver gases is oblique to the lower and upper walls of the passage. At later times, this shock wave turns and becomes normal to the upper and lower walls. Thus, for skewed geometry passages there is no obvious condition for minimizing the mixing losses caused by the inlet opening.

Received June 20, 1985; revision received Oct. 18, 1985.

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