Study on Combustion Termination of Solid Propellants by Rapid Depressurization

Y.Y. Shan* and C.C. Tao†
Chung-Shan Institute of Science and Technology, Taiwan, Republic of China

Abstract

AN experimental investigation of the extinction behavior of solid composite propellants (PBAN + AP) by rapid depressurization is made. An analytic procedure by an adiabatic process (or isentropic process) and Summerfield's burning rate law is taken to predict pressure decay. The vents' opening rate is assumed to be a parabolic function of time; also, a model of "adiabatic-isentropic combined process" is proposed for improving the predictions.

Contents

Ciepluch concluded that there was a minimum depressurization rate $(dP/dt)_c$ required to extinguish combustion,[1] that many solid propellant compositions might be susceptible to the reignition phenomenon, and that the residual chamber gas and the residual heat in the propellant surface were the primary sources of ignition energy.[2] Jensen and Brown[3] found that the exhaust pressure level could influence extinction and reignition behavior.

Experimental investigation of this study is achieved by using a test motor shown schematically in Fig. 1.

As shown, two additional vents on the head of the motor were blocked up with vent covers that were held in position with two U-clamp bends and two explosive bolts. The motor was depressurized rapidly by initiating the explosive bolts and opening the vents. A pressure transducer and a high-speed camera were used to record the pressure variation and extinction phenomena, respectively. The results are listed in Table 1.

It is found that the combustion of PBAN propellants was extinguished temporarily by opening suitable venting ratio ports on the motor head, but that reignition occurred because of residual heat feeding back to the propellant grain under the test environment of 1 atm. Furthermore, the reignition could be delayed by inserting vulcanized fiber between the free-standing grain and the motor case (with motors 2 and 4) because of the effects of reducing residual heat transfer from the motor case and hot gases.

In this investigation either an isentropic or an adiabatic process is assumed, and Summerfield's burning rate law is used to predict pressure decay. Besides, the venting ratio is assumed as a parabolic function of time[4] during the period of delayed time t_d before full opening of the vents.

The main assumption of isentropic pressure decay is that the extinction occurs immediately upon opening of the vents without time delay. For the case of adiabatic pressure decay,

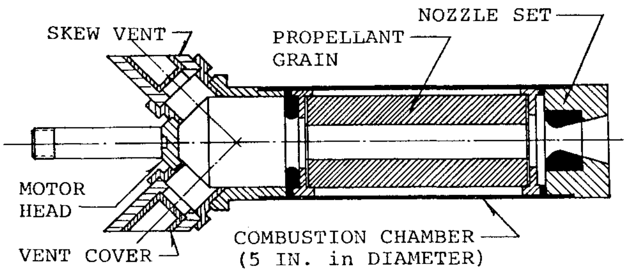

Fig. 1 Schematic of combustion termination test motor.

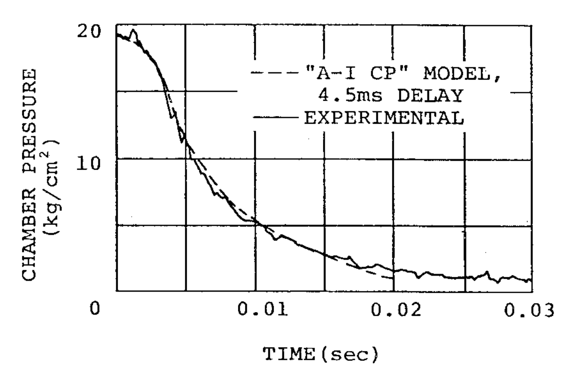

Fig. 2 Comparison of pressure decay by "A-I CP" model with experimental data ($K = 1.456$).

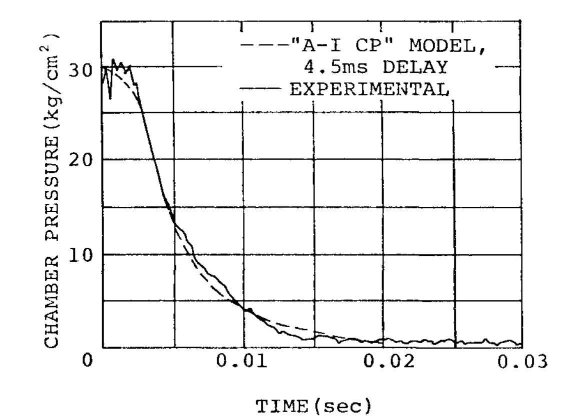

Fig. 3 Comparison of pressure decay by "A-I CP" model with experimental data ($K = 2.84$).

the phenomenon of combustion may be retained after the opening of the vents, while the temperature may vary during expansion. However, high-speed photographs obtained from static firing of test motor 2 indicate that the combustion did not extinguish immediately upon opening the vents, and the phenomenon of extinction occurred at 0.005 s later, which was approximately equal to the value of $\Delta t_{1/2} = 0.0048$ s measured from the recorded P-t trace. Therefore, a model of

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*Assistant Scientist.

†Associate Scientist. Member AIAA.

Table 1 Summary of combustion termination experiments

			Time length of extinction, s			
No.	K	Extinction or not	P-t curve measurement	High-speed photographs reading	$\Delta t^{1/2}$, s	dP/dt, kg/cm^2-s
1	2.84	Yes, but reignition	1.42	...	0.0044	3521.4
2[a]	2.0	Yes, but reignition	1.87	1.62	0.0048	2906.6
3	11.5	No	...	...	0.0034	4860.2
4[a]	1.456	Yes, but reignition	2.40	2.36	0.0059	1689.9

[a] The vulcanized fiber was inserted between propellant grain and motor case.

"adiabatic-isentropic combined process" is proposed as follows:

1) At $0 \leq t \leq \Delta t_{1/2}$, the propellant grain goes on burning and an adiabatic process is assumed. The equations of pressure decay rate, chamber temperature variation rate, and vents' opening rate are used for solution.

2) At $\Delta t_{1/2} < t \leq t_f$ (t_f = the final time when the propellant is almost extinguished), since the combustion of the propellant grain extinguishes gradually and the concept that the isentropic process predicts the immediate extinction upon opening the vents is usually considered, it is proposed that the importance of the adiabatic process is decreased and that of the isentropic process is increased. The expression is as follows:

$$P = P_{(A)}(1-Z) + P_{(B)}Z$$

where $P_{(A)}$ is the pressure obtained by solving adiabatic pressure decay; $P_{(B)}$ is the pressure obtained by solving isentropic pressure decay; and Z is the percentage of weight of the isentropic process, defined as

$$z = [(t - \Delta t_{1/2}) / (t_f - \Delta t_{1/2})] 100\%$$

Figures 2 and 3 show the results of the proposed model ("A-I CP" model) for different values of the venting ratio (K). As can be seen, the predictions are in good agreement with experimental data. However, the applicability of this model to different motor configurations needs further justification by more experiments.

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