DEVELOPMENT OF ALUMINIZED AND NONALUMINIZED COMPOSITE SOLID PROPELLANTS WITH LOW PRESSURE INDEX

[1]MANUPRASAD.E.S, [2]S.R.CHAKRAVARTHY

[1,2]Department of Aerospace Engineering, IIT Madras
E-mail: [1]manuprasades@gmail.com, [2]src@ae.iitm.ac.in

Abstract- Minimizing the pressure index of a composite solid propellant is of prime importance as far as the stability of solid rocket motor is concerned. Aluminized and non-aluminized propellants of different formulations are tested in window bomb and the burning rates are analyzed. A constant burning rate is obtained in the pressure range 60-80 bars for the propellants with low fine AP/binder ratio, ultrafine AP and cured by IPDI. This is termed as plateau burning and the pressure index is found to be minimal in the corresponding pressure range.

Keywords- Mid-pressure extinction, Pressure index, Plateau burning

I. INTRODUCTION

The high thrust provided by the solid propellants makes it prefer over any other propulsion system for a space launch vehicle. It is desirable to minimize the pressure index of a solid propellant to attain combustion stability. The burning rate of a solid propellant is given by,

$$r = aP^n$$

where a is a constant, P is the chamber pressure, and n is the pressure index. If n is zero, then the burning rate is independent of chamber pressure and equals to a, i.e., the burning rate is unaltered by the chamber pressure variations and remains the same for a range of pressures, which is called plateau burning.

Typical launch vehicles use solid rocket motors that contain composite solid propellants made up of ammonium perchlorate (AP) as oxidizer, and aluminium metal powder and a hydrocarbon polymeric binder as fuel ingredients, besides other minor additives. In order to maximize the solid loading of the propellant, and hence its density, a bimodal particle size distribution of AP is often used, comprising coarse AP and fine AP fractions. The combustion zone of a composite propellant is complex, consisting of multiple flames such as the monopropellant flame over the coarse AP particles, the leading edge of the oxidizer/fuel diffusion flames over the interfaces between the coarse AP particles and the surrounding matrix of fine AP, metal powder, and binder with additives, an outer diffusion flame trailing from the above leading edge flame, and a canopy premixed flame over the regions of the fine AP/binder matrix. It is observed that the interaction between the melt layer of the binder and fine AP content in the combustion zone is the key factor that leads to plateau burning. If the fine AP particle size is less than the binder-melt layer thickness, the free movement of fine AP particles will be possible through the melt layer. This creates local starving of fine AP, which causes the mid-pressure extinction in matrices. The propellants with same fine AP/ binder ratio, fine AP particle size, and curing agent have the plateau burning trends in certain pressure ranges. The prime objective of this work is to develop aluminized and non-aluminized plateau burning propellants and to establish their corresponding plateau burning pressure ranges.

II. EXPERIMENTAL DETAILS

2.1Propellant ingredients

All the six kinds of propellants tested are consist of Hydroxyl terminated polybutadiene (HTPB) as the pre-polymer(fuel), Ammonium perchlorate (AP) as oxidizer, Dioctyl Adipate (DOA) as plasticizer, Toluene Di-Isocynate (TDI) or Isoprene Di-Isocynate (IPDI) as curing agent, Ambilink as cross linking agent, Nonax-D as antioxidant agent and Al as metallic fuel in aluminized formulations.

2.2Propellant formulations

Different formulations of non-aluminized, aluminized propellants with 18 micrometer aluminium and 4.5 micrometer aluminium are analyzed in the present study. All the formulations have 86% solid loading and a bimodal AP distribution for effective packing. For TDI cured propellants, the binder consists of HTPB: DOA: TDI in the ratio 80:15:5 and for IPDI cured propellants, the ratio is HTPB: DOA: IPDI = 75.73: 18.39:5.88. The propellant formulations are given in table 1.

2.3Window Bomb

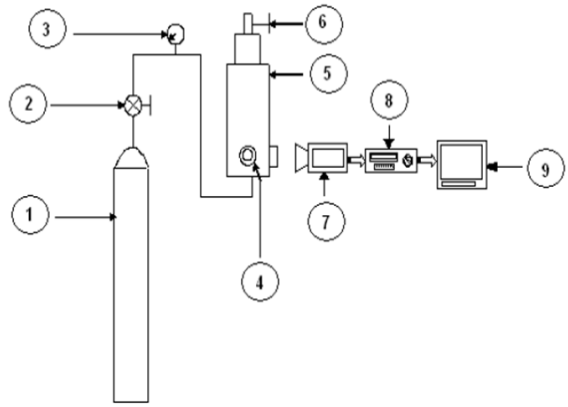
The window bomb is a simple technique to measure the propellant burn rate at different pressures. A propellant sample of dimension 5 mm × 5 mm × 12 mm with inhibited surfaces is burned vertically and the burn rate obtained by analyzing the video frame by frame. The main body of this setup is a thick stainless steel cylinder with two optical glass windows for illumination and access for

Table 1. Propellant formulations.

formulation	fAP/ Binder	Curing agent	fAP size (μm)	cAP size (μm)	Al %	Al size (μm)
P1	71/29	TDI	45-75	210-355	-	-
P2	60/40	IPDI	5-10	355-425	-	-
P3	71/29	TDI	45-75	210-355	15	18
P4	60/40	IPDI	5-10	355-425	15	18
P5	71/29	TDI	45-75	210-355	15	4.5
P6	60/40	IPDI	5-10	355-425	15	4.5

camera. The bottom piece has a pedestal to mount the propellant sample and chamber pressurization hoses. The cylinder is closed with a top plate where an exhaust hose and valve are connected to control the pressure inside the chamber. The high intensity light from a xenon lamp is sent through the optical illumination window and the propellant burning video is captured with a CCD camera through the other window. The schematic diagram of the window bomb is shown in figure 1.

The magnification of the camera is calculated by taking the images of a known distance. Experiments are repeated over different pressures and the burning rate is plotted against the pressure in a log-log plot. Thus the pressure index 'n' is given by the slope of the plot.



1. Nitrogen cylinder 2.Cylinder valve
3. Pressure gauge 4. Illumination window
5. Window bomb 6.Exhaust valve
7. CCD camera 8.Recorder
9. TV monitor

Figure 1. Schematic diagram of window bomb.

III. RESULTS AND DISCUSSION

3.1Matrices

The matrices of fine AP/Binder ratio from 55/45 to 75/25 are burned in window bomb and the result is shown in figure 2. These matrices are prepared with fine AP of size 5-10 micrometer and cured by IPDI.

The matrices 75/25 and 70/30 is burned completely in all pressures from 20 bars to 70 bars. The matrix 65/35 is quenched beyond 30 bars. The matrices 60/40 and 55/45 is started quenching at 30 bar itself. This self-quenching is called the mid-pressure extinction and it happens primarily due to the fine AP-Binder melt layer interactions. As we move from 75/25 to 55/45, the fine AP content decreases and correspondingly the binder content increases which make the fine AP movement in binder melt layer easier and thus the mid-pressure extinction range is shifting towards left as the plot proceed to bottom.

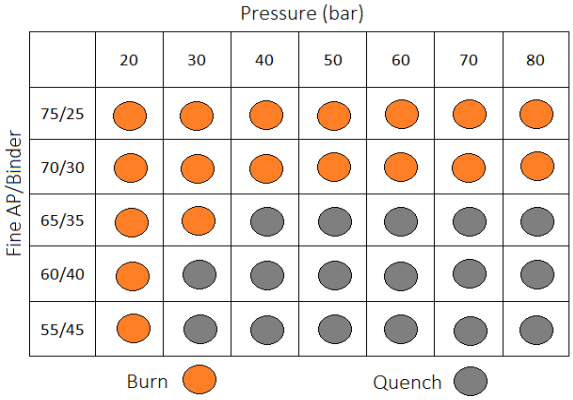


Figure 2. Matrix burning

3.2Propellants

The propellant burning rates obtained are shown in figure 3. The propellants P1, P2, and P3 are not showing any constant burn rate anywhere in the curve. They are propellants with higher fine AP/binder ratio, comparatively higher fine AP and cured by TDI. On other hand, the propellants P2, P4 and P6 show a constant burning rate over the pressure range 60-80. These propellants have lower fine AP/binder ratio, ultrafine AP and cured by IPDI.

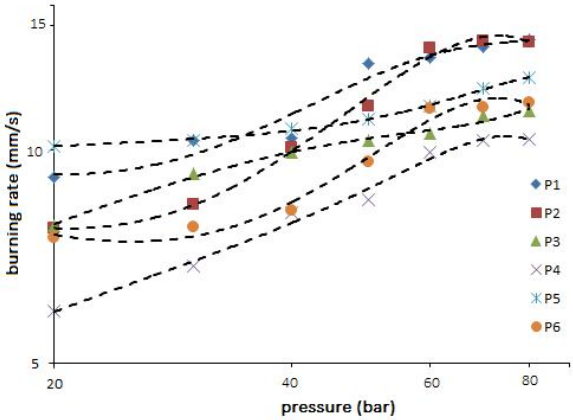


Figure 3. Propellant burning rates

The pressure index obtained for each sections of the curve is given in table 2.

Table 2. Pressure range and pressure index

Pressure Range (bar)	Pressure index "n"					
	P1	P2	P3	P4	P5	P6
20-30	0.30	0.19	0.43	0.36	0.04	0.08
30-40	0.03	0.65	0.23	0.60	0.13	0.19
40-50	1.08	0.61	0.17	0.2	0.14	0.71
50-60	0.11	1.03	0.12	0.84	0.23	0.96
60-70	0.23	0.15	0.38	0.24	0.39	0.01
70-80	0.19	-0.01	0.13	0.03	0.26	0.10

CONCLUSIONS

The plateau burning behavior of different propellants is analyzed and the major conclusions are as follows.

1. The mid-pressure extinction is observed even in low pressure regions while the fine AP/binder ratio decreases
2. A combination of low fine AP/binder ratio, very low micron fine AP and IPDI will yield constant burn rate in higher pressure range. The plateau burning pressure range is obtained as 60-80 bar.

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