Pressure Dependence, Propellant Composition, Particle Size & Effect of Catalyst on Burn Rate Study of AP-HTPB based Composite Solid Propellants

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Abstract— In the present investigation, an effort has been made to study pressure dependence, propellant composition, particle size and effect of catalyst on the burn rate of AP based composite solid propellant. The variation of oxidizer has been made 70%, 75% and 80% based on earlier experience of the loading of HTPB on the combustion characteristics of AP based composite solid propellants. The particle size of the oxidizer in the present formulation is taken to be 44 μm and 149 μm respectively. The bimodal AP are taken with mess size 150 and 300.

Key words: Pressure Dependence; Propellant Composition; Particle Size; Burn Rate; AP; HTPB, Fe_2O_3

I. INTRODUCTION

The burning of solid propellants occurs in a very thin region at a surface of the charge. Some of the heat from the burning gas is transferred into the charge, raising its temperature. There is a temperature gradient through the charge, the temperature adjacent to the burning surface being that of the burning gas (flame temperature), and the temperature at some distance inside the charge being that at which the charge was before the motor was fired. As burning proceeds and the burning surface recedes into the charge, at some fixed point in the charge the temperature rises. The propellant softens and melts. This decomposes the gases, which react chemically and ignite, burning at the flame temperature. Meanwhile, the propellant at some point has begun to soften and will go through the same reactions. Thus burning continues, and the burning surface recedes steadily into the charge. The burning surface regresses by burning in parallel layer in a direction perpendicular to the surface itself. The rate at which the surface regresses due to burning or the rate at which the flame front propagates to the free surface of the grain is called the “linear burning rate” of the propellant.

A. Dependence of Burn Rate on Pressure

The burning rate dependence on pressure can be expressed as

$$r = a * P_c^{\,n} \qquad \text{(Equation 1)}$$

This is known as De Ville’s or St. Robert’s law. This happens to be very accurate for all types of propellant and is generally used. In this expression ‘n’ called the pressure exponent or the combustion index is essentially independent of the initial grain temperature but describes the influence of rocket chamber pressure on burning rate. The other constant ‘a’ called temperature coefficient is influenced by ambient temperature.

B. Dependence of Burn Rate on Propellant Composition

Propellant composition has a marked influence on the burning rate. All attempts have so far converged in the search of high performance propellants, and they concluded that the burning rate increases with the increase in percentage of oxidizer but only upto a certain limit.

C. Dependence of Burn Rate on Particle Size

The performances of composite propellants have been shown to be directly proportional to the oxidizer content and particle size. The particle size of the oxidizer in the present formulation is taken to be 44 μm and 149 μm respectively.

Renie[13] have investigated the effect of oxidizer size and distribution on non- aluminized composite propellants. They used a new mathematical model called as ‘petite ensemble model’. They showed that the oxidizer particle size and distribution have profound influence on burning rate, pressure exponent ‘n’ and temperature sensitivity. They also showed that the combustion parameters were strongly dependent on coarse-to-fine and the mean diameter of the fine fraction.

D. Dependence of Burn Rate on Effects of Catalyst

The catalytic effect in certain materials has long been noted in solid propellants. A catalyst is a material that increases the reaction rate of a chemical reaction but remains unchanged at the end of the chemical reaction. Ferric oxide (Fe_2O_3) is taken as the catalyst in the present formulation.

II. EXPERIMENTAL

In the present work, it has been attempted to use AP - HTPB composite solid propellant and study their combustion aspects. The different composition were used for experimentally studies with prior experience of the mechanical and combustion behavior of AP - HTPB propellant at the laboratory. The bimodal AP is taken with mess size 150 and 300. The AP are loaded at 70, 75 and 80 percent’s by weight in HTPB processed with DOA as plasticizer, TDI as curing agent and glycerol.. The basic formulations of the samples consisted of AP – HTPB + catalyst are shown in Table 1.

S.No	AP (wt%)	HTPB (wt%)	DOA (wt%)	TDI (wt%)	Glycerol (wt%)	Fe_2O_3 (wt%)
1	70	21.59	6.48	1.70	0.23	-
2	75	17.99	5.40	1.42	0.19	-
3	80	14.39	4.33	1.13	0.15	-
4	70	21.59	6.48	1.70	0.23	3
5	75	17.99	5.40	1.42	0.19	3
6	80	14.39	4.33	1.13	0.15	3

Table 1: Formulation of Uncatalyzed and Catalyzed AP-HTPB based Composite Solid Propellants

A. Measurement of Burning Rate

The burning rates of AP-HTPB composite propellants with and without catalysts have been determined at ambient condition and at different pressures, 2.06, 4.76 and 6.89 MPa, using a conventional strand burner. Nitrogen gas has been

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used to pressurize the bomb. The dial type pressure gauges have been used to record incoming pressure and pressures in bomb and line. A surge tank has been provided in the set- up to ensure that a strict pressure level is maintained in the bomb. This has been shown clearly in figure 1 and figure 2.

The propellant strands, having two fine drilled holes at a distance of 5 cm to position the fuse wires, were installed in the bomb and igniter wire was suitably placed at apex of the strand. The cap, with the provision for electrical connections in it was tightened on to the bomb. The bomb was then pressurized with nitrogen gas to required pressure level. The necessary electrical connections were made and the strand was ignited to record time with the help of an electrical timer. Similar procedure has been followed for each strand. The burning rates were then determined from the time elapsed between the two fuse wires.

Fig. 1: High Pressure Strand Burner Setup

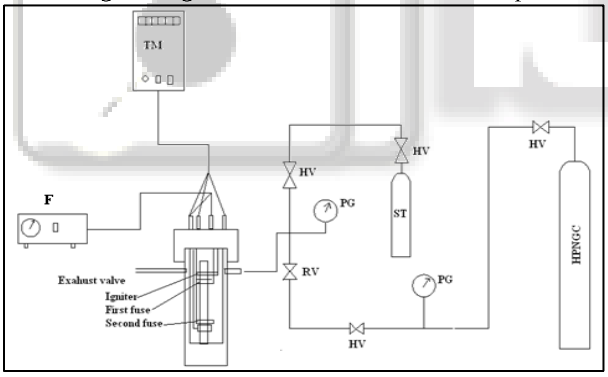

Fig. 2: Line diagram of High Pressure Strand Burner

III. Results & Discussion

A. Burning Rate Studies of AP-HTPB Composite Solid Propellants

The burning rate measurements were carefully carried out by using strand burner at 2.068, 4.765 and 6.895 MPa by pressurizing nitrogen gas. The pressure dependence of burning rate of AP - HTPB has been shown in table 4 and 5. It is found from that the burning rate of propellant containing 80% AP loading have been found to be higher than the corresponding propellants of 75% and 70% AP loading (figure 3). At ambient pressure the burning rate of the composite solid propellants are increasing as the AP loading is increases. But as the 3% ferric oxide is added in same compositions it gives high burn rate at 70% AP loading as compare to others AP - HTPB based composite solid propellants. The experiment is conducted on 2.068, 4.765 and 6.895 MPa pressure. The burning rate increases with increase in pressure and 80% AP - HTPB based composite solid propellants with ferric oxide (figure 3) shows drastic variation from 9.250 to 44.407 mm sec^{-1} at 1000 psi chamber pressure. As the preparation is very difficult for 80% AP - HTPB based composite solid propellants with and without ferric oxide, which gives higher value of pressure index i.e. 0.526. The temperature coefficient is minimum in75% which shows lowest performance with respect to the others. A comparative graph has been plotted in figure 3.

The burning rate of the propellant is found to increase with combustion chamber pressure. The increase in the rate of burning with pressure may be attributed to the more contribution of reaction kinetics process of controlling of burning rate when compared with diffusion controlled process at high pressures.

Types of Propellant	Burning Rate (mm sec^{-1}) Pressure (MPa) 0.101	4.760	2.068	6.895	a	n
70% AP-HTPB	4.16	6.76	7.26	9.25	6.2	.098
70% AP-HTPB with 3% Fe_2O_3	5.55	7.87	8.13	10.63	6.7	.203
75% AP-HTPB	4.26	5.54	7.02	7.96	5.02	.136
75% AP - HTPB with 3% Fe_2O_3	4.44	13.04	14.91	17.54	10.31	.323
80% AP - HTPB	4.87	13.97	24.58	33.31	10.19	.433
80% AP - HTPB with 3% Fe_2O_3	5.12	28.2	35.68	44.40	19.24	.52

Table 2: Burning Rate of Uncatalyzed and Catalyzed AP-HTPB based Composite Solid Propellants at Different Pressures

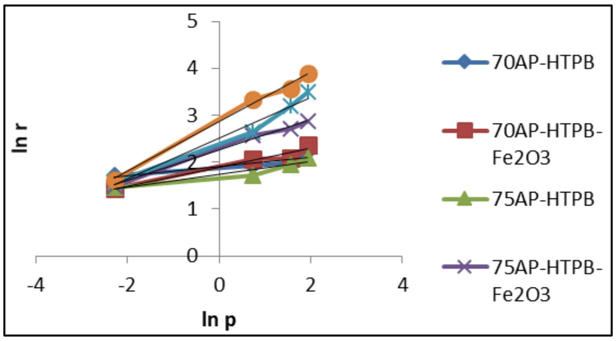

Fig. 3: Comparison of Burning Rate 70, 75 & 80% of AP-HTPB Composite Solid Propellant with Catalyst

Types of Propellant	ln r ln p -2.2920	0.7265	1.560	1.9307	ln a	n
70% AP - HTPB	1.713	1.916	1.982	2.224	1.829	0.098
70% AP - HTPB with 3% Fe_2O_3	1.426	2.063	2.095	2.364	1.915	0.203
75% AP - HTPB	1.450	1.713	1.949	2.074	1.613	0.136

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75% AP - HTPB with 3% Fe_2O_3	1.490	2.568	2.702	2.864	2.333	0.323
80% AP - HTPB	1.584	2.636	3.202	3.496	2.322	0.433
80% AP - HTPB with 3% Fe_2O_3	1.633	3.339	3.574	3.900	2.956	0.526

Table 3: Pressure Dependence of Burning Rate of AP - HTPB based Composite Solid Propellants at Different Pressure

IV. Conclusions

1) The burning rate of AP - HTPB composite solid propellants results very impressive data with expected combustion index values.
2) It was observed that the burning rate increases with increase of chamber pressure and also, the combustion pressure rate increases with increase in oxidizer loading for all the cases. Further, the phase transition, melting and decomposition processes of the oxidizer are pressure sensitive and associated peaks register a positive temperature shift with pressure.
3) Conversely, the addition of catalyst with 3 wt% ferric oxide especially in high pressure region shows drastic increase in burning rate with increase in AP % loading.

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