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Effect of Propellant Composition to the Temperature Sensitivity of Composite Propellant

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Abstract. The propellant composition is one of several parameter that influencing the temperature sensitivity of composite propellant. In this paper, experimental investigation of temperature sensitivity in burning rate of composite propellant was conducted. Four sets of different propellant compositions had been prepared with the combination of ammonium perchlorate (AP) as an oxidizer, aluminum (Al) as fuel and hydroxy-terminated polybutadiene (HTPB) as fuel and binder. For each mixture, HTPB binder was fixed at 15% and cured with isophorone diisocyanate (IPDI). By varying AP and Al, the effect of oxidizer- fuel mixture ratio (O/F) on the whole propellant can be determined. The propellant strands were manufactured using compression molded method and burnt in a strand burner using wire technique over a range of pressure from 1 atm to 31 atm. The results obtained shows that the temperature sensitivity, a, increases with increasing O/F. Propellant p80 which has O/F ratio of 80/20 gives the highest value of temperature sensitivity which is 1.687. The results shows that the propellant composition has significant effect on the temperature sensitivity of composite propellant

1. Introduction

The effect of propellant composition on burning characteristic of composite propellant has been long recognized. Bozic et al [1] reported that, the propellant composition is one of the several parameter that influence the temperature sensitivity. An understanding of this effect is important for improving the capability to the selection of the proper formulations to satisfy specific needs. The previous studies proved that temperature sensitivity can be significantly lowered by utilized larger percentage of aluminum [2]. Then, several researches [1, 3-4] mention that varying oxidizer-fuel mixture ratio will give a different value of temperature sensitivity. The objectives of this study are to determine the temperature sensitivity of four different compositions of aluminized AP/HTPB composite propellants. The scope included measuring burning rate over a range of pressure from 1atm to 31atm, while varying the percent of aluminum and ammonium perchlorate.

2. Methodology

2.1. Propellant selection composition

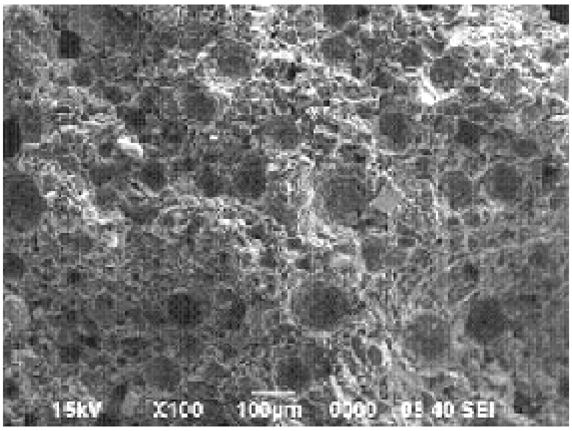
The specific impulse (Isp) and the burning rate are among the most important performance parameters of propellants. High Isp is required to obtain optimum performance of a propellant.The theoretical Isp was estimated using NASA CEC71 program [5], a computer program for rocket performance. The same program was also applied by several researchers [6-7] to estimates the performance characteristics of AP/HTPB based propellant. The propellant used in this experiment was composite propellant consisted of ammonium perchlorate (oxidizer), aluminium (fuel) and hydroxy terminated polybutadiene, (HTPB) binder (fuel). Due to the poor processibility and mechanical properties of the propellant formulation with higher solid loading fraction [3, 8] and reduced Isp of the propellant with low oxidizer fraction, the range of composition tested was limited. Only four composition were selected and finalized which have O/F; 60/40, 66/34, 74/36 and 80/20 as shown in Table I. For each of the compositions, the percentage of HTPB binder was set constant at 15%. Initially, the percentage of Al used was 25% in the mixture and subsequently decrease until it reached 5% with proportional increase in AP. The formulation codes were named according to the percentage of AP applied.

Table 1. Formulation of the propellant.

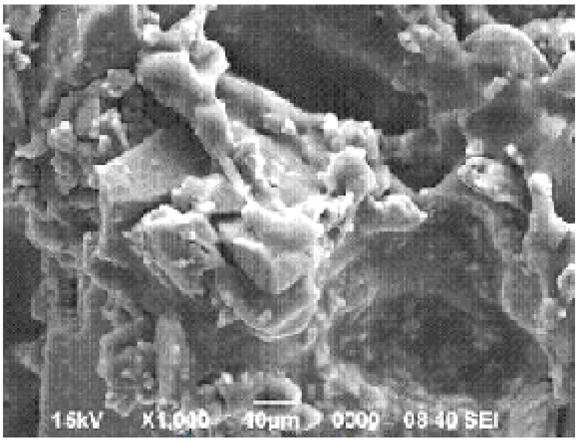
Formulation code	AP (%)	AL (%)	O/F
p80	80	5	80/20
p74	74	11	74/26
p66	66	19	66/34
p60	60	25	60/30

2.2. Propellant preparation

The first step in mixing process is to produce the binder by mixing HTPB with IPDI accordingly. The ingredients were mixed together using a glass stirring rod in an agitating and swirling motion, similar to the method reported by Matthew Stephens et al. [9]. Al was then added to the binder and blended together until all the Al powder was coated by the binder. Next, the AP was added according to the desired formulation and the mixture was again stirred until a uniform consistency was achieved. Without degassing, the propellant was compressed into a straw mould which has 70mm length and 5mm diameter. There were 2 main reasons for choosing these dimensions. Firstly, to minimize the pressure and temperature increase in the strand burner combustion chamber during testing. Depending on the composition of mixture, combustion of 2.54 cm (1 inch) strand could increases as much as 10-20% pressure inside the burner [10]. Secondly, this small size reduces material cost and improves safety. Each of 100 grams of mixtures can produce approximately 27 strands of propellants. The length of the strand burnt is the importance parameter to be measured for burning rate calculation, while the size and shape of the strand is less significant [10-11]. The strands were then transferred to the oven and cured at 64˚C for 5 days. The strands were visually inspected and were rejected if cracks, pores, or shape irregularities were seen. A cross-sectional view of the propellant was observed under SEM photographs as shown in Fig. 1 in order to investigate the structure of propellant matrix.



a) Magnified 100X.

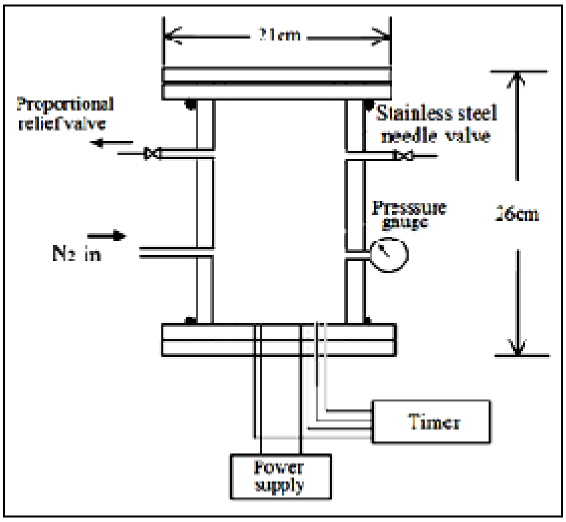


b) Magnified 1000X

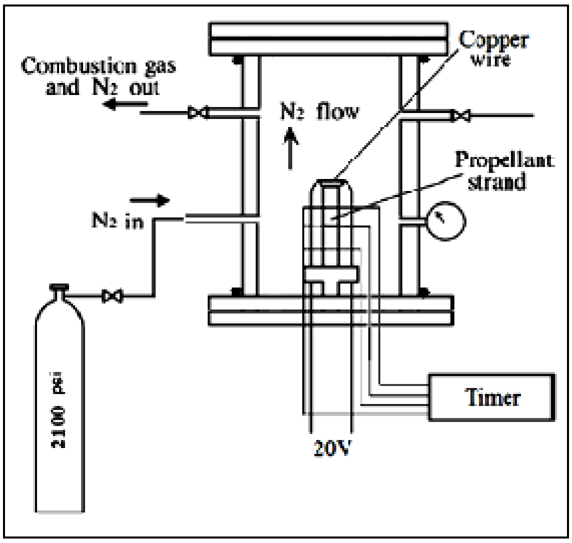
Figure 1. Cross sectional view of propellant p80

3. Burning rate measurement

The burning rate measurement was carried out with a strand burner which was pressurized by nitrogen gas. The strand burner was designed to handle test pressures up to 38atm (550 psi). The body, flange and both end cap are made of low carbon steel. The 23 cm long cylinder has an inner diameter of 10 cm and an outer diameter of 13 cm, offering a wall thickness of 1.5 cm thickness. Each end cap is 1.5 cm thick, making the overall length of the burner 26 cm as shown in Fig. 2(a). Both end caps are square with side length of 21 cm. The propellant strand was fixed to the end cap using strand holder made of 5mm low carbon steel nut. Nitrogen and combustion products escape to the atmosphere via a stainless steel proportional relief valve as shown in Fig. 2(b).



a) Assembly view.



b) Schematic diagram.
Figure 2. The strand burner facilitie

Wire technique was used to measure the burning rate. Each strand was 5 mm diameter and 70 mm in length. Three small holes were accurately placed along the strand length using a needle. An igniter and two fuses wires were passed through these holes and connected to a power supply and electronic timer respectively. All wires were of the same type of 38 S.W.G. tinned copper wire with 0.152 mm thickness, the same type of igniter wire used by Rodolphe et al.[10].The strand is mounted vertically and is ignited at the top end using electrical current. The burning rate was measured for several combustion pressure ranging from 1 atm to 31 atm. It was determined from the period it took for both fuses separated at a distance of 50 mm apart to cut-off. Both ends were left with 10mm distance to avoid extinction transient [12]. Generally, three strands established the burning rate at a single pressure level and repeatability of the burning rates was observed within 5% and is acceptable according to K Jayaraman et al. [13]

4. Result and discussion

The data of temperature sensitivity for each of formulations were collected as shown in Table 2 and were used to plot the graph in Figure 3 and Figure 4.

Table 2. Temperature sensitivity of the propellant.

Formulation code	Temperature sensitivity, *a*
p80	1.687
p74	1.578
p66	1.466
p60	1.455

Figure 3 shows that with small quantity of Al, i.e. less than 19%, will has little effect on the combustion mechanism of propellant, further increasing the amount of Al has resulted in the decreasing in temperature sensitivity. These observation also confirm the observation made by T Godai and M Shimizu[8]. The discussion from previous study [14-15] reported that, the presence of aluminum particles in propellant act as heat sinks by absorbing energy released by gas phase reactions and decrease the burning rate. As a result, reduces the burn rate temperature sensitivity. It means that, the propellant becomes less sensitive to the temperature.

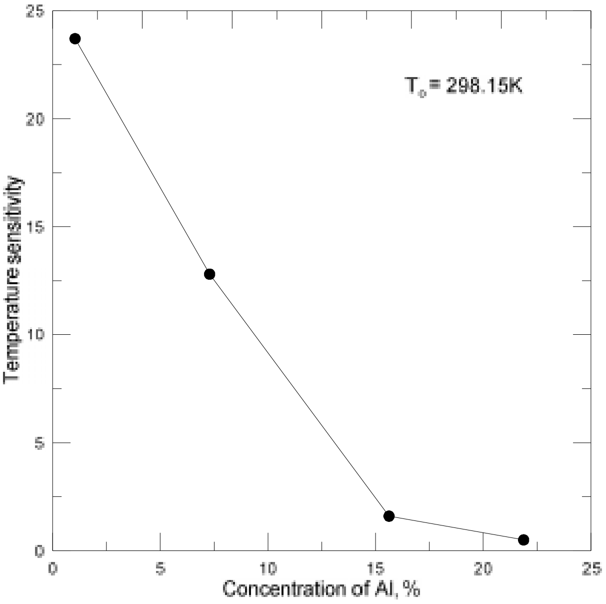


Figure 3. Effect of Al concentration on temperature sensitivity

Figure 4 shows that the temperature sensitivity will increase by increasing the percentage of ammonium perchlorate because of the fast reaction rate due to the high flame temperature of propellants containing higher loading of oxidizer [8]. A experimental result in Figure 4 shows that by increasing 20% of the oxidizer from p60 to p80, increase the pressure sensitivity by 12% which is similar with the study made by Makoto and Hirotatsu [16].

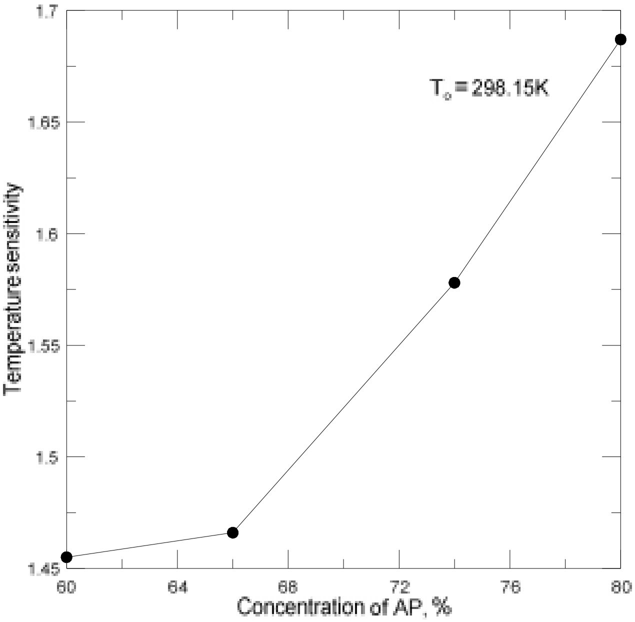


Figure 4. Effect of AP concentration on temperature sensitivity

5. Conclusion

The relationship between the temperature sensitivity in burning rate rule and different propellant composition of composite propellant was experimentally investigated. The results obtain shows that, the temperature sensitivity increase with increasing oxidizer-fuel ratio.

6. Acknowledgment

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