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Burning Characteristic of Ap68al15htpb17/13 Propellant At 1 Atmospheric, 2 Bar and 4 Bar

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Abstract

This project focused on determining the burning characteristic of AP based propellants developed at Universiti Teknologi Malaysia including their fabrication methods and burning rate. Based on the curing test, it was found that the propellants had to be cured in the oven for at least seven days to ensure a stable burning rate. The burning rate test was conducted using propellant strands that were fabricated using press molding method and burnt in a strand burner or Crawfard Bomb at chamber pressures of 1 atmospheric, 2 bars and 4 bars. The results were observed following the Saint-Robert's and Veille's equation, given by $r = aP^n$., a = 0.3914 and n = 0.436.

Keywords: AP based propellants, curing test, Crawford bomb

1. INTRODUCTION

Solid propellants are widely used as solid fuels for rockets and missiles in both military and space application. Composite propellants are grouped into the solid propellant's family where it consists of oxidizer, metal fuel, binder, catalyst and other materials. Ammonium perchlorate (AP) is one of the major ingredients in mixing composite propellants, where it is extensively used as an oxidizer in solid propellants because of its ability to self-stabilize and control the burning rate of the propellants [1].

The burning rate of solid propellant is one of the important parameters that needs to be taken into account in order to produce a high performance propellant. The burning rate of propellant is affected by its initial propellant temperature, chamber pressure, propellant composition (oxidizer-fuel mixture ratio), particle size of AP and the type of binder used. The burning rate of the propellant can be calculated using the equation $r = aP^n$, where a is the empirical constant, which is a function of temperature, and n is the pressure exponent [2]. The equation clearly shows that the initial grain temperature and pressure are the main parameters that affect the burning rate since the composition of propellant is fixed.

2. METHOD

2.1 Mixing Procedure

The tested propellant in this study was made from mixture. After both HTPB and IPDI had been weighed, the HTPB was first poured into a bowl, followed by the IPDI. The mixture was then stirred by using a glass rod until the mixture becomes homogeneous and blended completely. Next, Al powder was added into the binder and the stirring process continued until all the Al powder completely coated onto the binder. Finally, AP powder was added to the mixture. The AP powder was sieved first before mixing with the mixture in order to obtain a finer particle of AP. All the mixture was then stirred until they completely blended with each other.

2.2 Compression and Curing

The mold was made from 6mm diameter soda straws, with length set to 80mm. The mold was punched on its wall using needle to create small holes on the straw wall to ensure trapped air could be removed during compression. After loading the propellant into the mold, the propellants were compressed using manual compression machine. The optimum compression pressure for this AP based propellant was about 0.48 MPa. Then, the propellant strands were wrapped with white tape to avoid the propellant from flowing out from the mold before curing the propellants in oven at 63°C for seven days. After seven days, the mold together with the white tape was removed. The dimension of the fabricated propellant is as shown in Table 1.

Table 1: Dimension of fabricated propellants

Length	75 mm
Diameter	6 mm
Average Mass	3.4 grams
Volume	2120.58 mm^3
Density	1603.34 kg/m^3

3. EXPERIMENT

3.1 Propellant Set Up

This project used fused wire technique to measure the burning rate, where copper wires were used for ignition, start and stop fuses. Initially, three small holes were accurately punched along the strand using needle. For the start and stop wire, a 38 S.W.G. tinned copper wire with 0.152 mm thickness was inserted into the strands. For the ignition wire, a thicker copper wire was used to provide high current flowing through it. The top hole for ignition was punched about 2 mm from the top end of the strand. Then, 10 mm and 15 mm from both top end of the strand, another two holes were punched for the start and stop wire. Figure 1 shows the complete setup for the propellant strand.

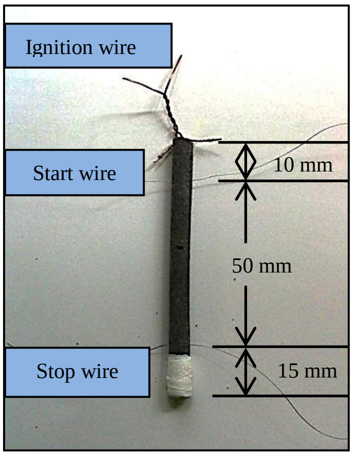

Figure 1. Propellant strand

Before placing the propellant strand on the mounting, the end of the strand was wrapped with white tape to ensure the strand stand firmly and withstand the inlet and outlet flowing of Nitrogen gas.

3.2 Strand Burner Set Up

The strand burner used in this project was the Crawford Bomb, designed based on the measurement method suggested by Crawford et. al. [3]. The low pressure Crawford Bomb used in this project was designed for small sample combustion of a propellant strand (6 x 75 mm or about 3.67 g) in a continuous inert gas flow for pressure up to 38 atm (550 psi). The schematic diagram of the Crawford Bomb can be seen in Figure 2. Figure 3 shows the propellant strand attached to the mounting stand. The Crawford Bomb chamber was placed on top of the mounting stand and it was sealed with eight bolts and nuts around it. Nitrogen gas was used to pressurize the Crawford Bomb chamber. The burner was installed with a stainless steel proportional relief valve and stainless steel needle valve to control the pressure inside the burner, so that a steady flow of nitrogen could be produced and to regulate the pressure inside the chamber.

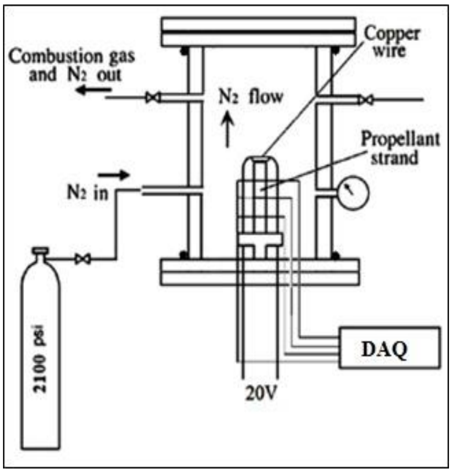

Figure 2. Schematic diagram of Crawford Bomb

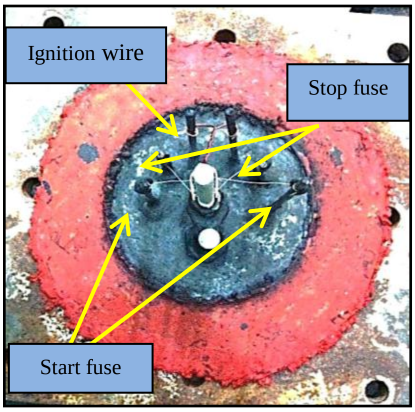

Figure 3. Mounting stand configuration

3.3 Instrument Set Up

Below the mounting stand were terminals for ignition, start and stop fuse. The start and stop terminals were connected to the Data acquisition system (DAQ) and the computer to measure the burning time, while the ignition terminal was connected to a high current generator. National Instrument LabVIEW 2009 software was used to measure the propellant's burning time.

3.4 Burning Rate Test

For analyzing burning at atmospheric condition, the propellants were burnt on the mounting stand alone. For 2 bar and 4 bar testing, the propellants were burnt in a complete Crawford Bomb chamber. Each strand was ignited using electrical current supplied from the voltage generator. Basically, the timing of burning rate started when the strand burnt the start fuse and stopped when it reached the stop fuse. The National Instrument LabVIEW 2009 software functioned to record the burning time of the propellant.

3.5 Propellant curing test

This test was basically to measure how long the propellants need to be cured in the oven before it can be used for testing. Initially, the propellants were fabricated using the same method as shown above. Starting from day three until the eleventh day, the propellants were tested for their burning rate at atmospheric condition. Before testing the propellant, the initial propellant temperature was measured and kept at temperature of 29°C.

4. RESULT AND DISCUSSION

4.1 At Atmospheric Condition

The burning rate of the 50 mm long propellant was obtained using the formula:

$$r = \frac{L_p}{t_b} \qquad (1)$$

where, L_p is the length of propellant and t_b is the burning time. The result of the preliminary testing is as tabulated in Table 2.

Table 2. The results of preliminary testing

Test	Time of experiment	Temperature, (°C)	Burn Rate,r (mm/s)
1	10.50 a.m.	28	2.32
2	3.23 p.m.	30	2.61
3	3.45 p.m.	30	2.79
4	4.12 p.m.	32	2.83

The burning rate of the propellant that was burnt in the morning was lower compared to the propellants that were burnt in the evening. This is because the propellants were coated by the HTPB, which is a polymer. This polymer becomes soft at high temperature, thus will enhance the flame to burn the propellants faster.

4.2 Propellants Curing Test

The result of this test was then plotted into a graph as shown in Figure 4. The graph shows that the burning rate of the propellant stabilized after seven days of curing in the oven. The seven days of curing made the propellant to have almost constant burning rate at 2.36 mm/sec with ±4% to 6% of error. Thus, this test indicates that the fabricated propellants need to be cured at least seven days in the oven before the test for its burning rate characteristic can be done.

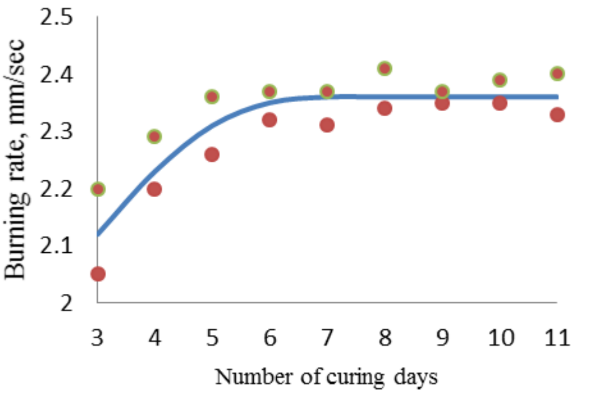

Figure 4. Effect of number of curing days on burning rate

Crawford Bomb Test

Similar to the curing test above, all the tests were conducted with the propellant's initial temperature of about 29°C in order to keep the initial grain temperature constant. Figure 5 shows the burning rate and pressure relationship obtained from this test.

According to Holzmann [4], there is generally a practical lower limit to the chamber pressure in a rocket motor, since at very low pressure in an enclosed space, a solid propellant may either burn inefficiently, unsteadily, intermittently, or not at all.

Increment of burning rate alongwith high pressure had been introduced because at high pressure, the flame would be thin and very close to the surface of the propellant. Once the propellant was ignited, the flame would enhance the rate of heat transfer and burn the propellant vigorously, leading to a higher burning rate.

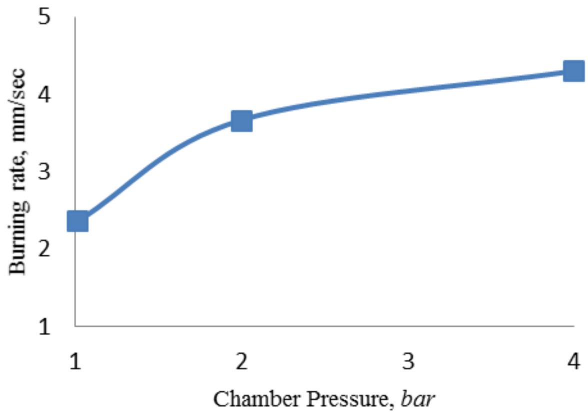

Figure 5. Burning rate- chamber pressure relationship

On the other hand, the value of pressure exponent, *n*, was obtained from the relationship between the combustion-pressure test and the propellant's burning rate.

$$r = aP^n \qquad (2)$$

Then, Equation (2) was changed into log form;

$$\log r = n \log P + \log a \qquad (3)$$

From linear equation;

$$y = mx + c \qquad (4)$$

By comparing Equation (3) with (4), the values of *a*, P and *n* could be determined from the graph, as shown in Figure 6.

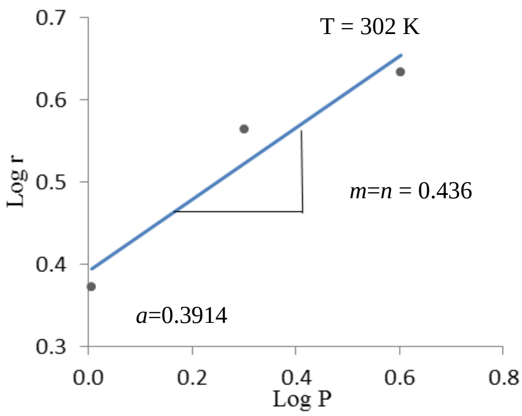

Figure 6. Logarithmic plot of burning rate of the propellants

The empirical constant obtained was a = 0.3914 and the pressure exponent was n = 0.436, which gave a linear equation;

$$y = 0.436x + 0.3914$$

From the theory, the value of n is mostly within the range of 0.2 to 0.8 for normal burning characteristic. According to Sutton [1], for the HTPB/AP/AL type of propellant, the normal pressure exponent should be around 0.4 while Amir Aziz [5] mentioned that, for a stable operation, the pressure exponent of a burning rate should be within a range of 0.2 to 0.6. The value of the empirical constant, a, is also accepted since the initial grain temperature was measured and fixed at 29°C before every testing. Anyhow, the propellant's temperature did change slightly when the Crawford Bomb was pressurized by nitrogen gas, but this minor error can be neglected.

The performance parameters of the propellant were obtained using both CHEM software and manual calculation. CHEM software is a speciallized chemical equilibrium software written based on NASA Computer program CEA (Chemical Equilibrium with Applications) [6]. However, not all parameter could be obtained from CHEM software because the chamber pressure used for this project was too low. Table 3 shows the results from calculation and CHEM software.

Table 3. Results of Parameter from Calculation and CHEM Software

Parameter	Calculated	From CHEM
Chamber temperature	3059 K	N/A (assumed 3059 K)
Exhaust temperature	2379.73 K	2419.73 K
Characteristic exhaust velocity	1522.31 m/s	1546.06 m/s
Effective exhaust velocity	3205.74 m/s	3347.76 m/s
Maximum Thrust Force	0.140 N	0.146 N
Specific impulse	326.76 sec	341.26 sec
Thrust coefficient	2.11	2.17
Mach number of the flow at the exit	1.6	1.6

5. CONCLUSION

The AP68AL15HTPB17/13 solid propellant has been developed and tested for its burning rate characteristics at three different pressure conditions. When tested at atmospheric condition, the result showed that the propellant was only affected by the initial propellant temperature since the tests were conducted at different time with different surrounding temperature.

From the burning rate test at 2 bar and 4 bar chamber pressure, it was found that the pressure and the initial grain temperature were the parameters that affected the burning rate of the propellant. The results showed that the propellants had a normal burning characteristic at low pressure chamber with pressure exponent, n, equal to 0.436 which lay within an acceptable range.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Sutton, G. P. (1991). *Rocket Propulsion Element 6th Edition*. New York: John Willy & Sons.

[2] Davenas, A. (1993). *Solid Rocket Propulsion Technology*. Oxford: Pergamon Press Ltd.

[3] Crawford B. L., Jr., Huggett C., Farrington D., and Wilfong R. E. (1947). *Direct Determination of Burning Rates of Propellant Powders*. Analytical Chemistry, Vol. 19, No. 9.pg. 630-633.

[4] Holzmann R. T. (1969). *Chemical Rockets and Flame and Explosive Technology*. Marcel Dekker, Inc.

[5] Amir Aziz (2001). *Combustion Characteristic of Ammonium Perchlorate Based Solid Rocket Propellant*. Master desertation, Universiti Teknologi Malaysia, Skudai.

[6] Sanford G. and Bonnies J. M. B. (October 1994). *Computer Program for Calculation of Complex Chemical Equilbrium Composition and Application, I Analysis*, NASA Reference Publication 1311, U.S.