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Analysis of Material Variations (Ammonium Perchlorate / Aluminum / Epoxy) And Pressure on Propellant Combustion Speed

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ABSTRACT

Suboptimal combustion rates can reduce rocket performance and increase safety risks, so material and pressure analysis is critical for more efficient and safer propellants. The aim of this research is to understand the effect of material and pressure combinations on propellant combustion speed in order to develop more efficient and safer propellants. This research uses propellant, nickel wire and lead, as well as measuring instruments, compressors, cameras and electricity sources. A comparative analysis of propellant combustion speed was carried out with variations in AP/Al/Epoxy materials and pressure variations. The research results show that the higher the pressure, the greater the combustion speed. Based on the research results, the relationship between the air pressure provided is directly proportional to the combustion speed and the propellant mass flow rate. The greater the pressure applied, the higher the combustion speed and propellant mass flow rate. The best performance is found in propellant B with a value of n = 0.44. A constant value close to 0 (zero) indicates a much more sensitive level of propellant sensitivity. The resulting mass flow rate at an initial atmospheric pressure of 0.332 gr/s and at an initial pressure of 5 bar is 0.791 gr/s.

Keywords: Ammonium Percrolate, Aluminum, Epoxy, Fast Combustion, Pressure

1. INTRODUCTION

A non-optimal combustion speed can result in less than optimal rocket performance and potential safety risks. Therefore, an in-depth analysis of how material combinations and pressure variations can affect combustion speed is essential for the development of more efficient and safer propellants.

Composite solid propellant (CSP) is the main energy source for rocket propulsion in military and space applications [1], [2], [3]. CSP is a recommended propellant in the field of solid rocket propulsion for tactical missiles and launch vehicle propulsion. CSP has slightly lower performance than complex liquid rocket engines, but CSP has the advantages of simple, reliable and chemically/mechanically stable design, high energy density, high reliability, good performance characteristics, and can be stored for a long time. long term [4], [5].

Modern rockets and missiles widely use composite propellants that essentially consist of an oxygen-rich solid oxidizer (65%–90%) that provides oxygen (O2) for oxidation purposes, an organic polymer that serves as a binder and a flammable gas (8%– 15%), and metal fuel (10%–20%) which produces additional heat energy to improve propellant performance [6], [7]. The propellant system consists of ~70% oxidizing particles (ammonium perchlorate, AP) and ~20% fuel particles (Aluminum, Al) embedded in 10 % hydroxyl terminated polybutadiene (HTPB) binder [8], [9].

Ammonium perchlorate (NH_4ClO_4, AP) has a heat release of 500–800 J/g and a positive oxygen balance of 34% which is considered as the main solid oxidizer because it has a high composite propellant mass (more than 70%) [10]. AP is very important for increasing the efficiency of energy release reactions (decomposition) and combustion [11], [12]. The properties of propellant composites are significantly influenced by AP decomposition [13].

AP and HTPB are the most widely used combination of oxidizer and binder in CSP [14]. At high temperatures far above the transition temperature of solid glass propellant. The higher the loading speed, the greater the breaking strain. At high temperatures, the entropy of the polymer chain cracks, causing damage to the HTPB binder [15], [16]. So innovation is needed to replace HTPB as a binder in the manufacture of solid propellant.

In the formation of CSP, heterogeneous propellant grains are formed when the oxidizer and fuel crystals are firmly bound by a synthetic polymer (or plastic) binding matrix, such as epoxy [17]. Epoxy resin is a polymer adhesive material. Epoxy-based composite materials play an important role as a binder [18], [19]. Epoxy has strong bonds, stable chemical structure, high mechanical strength, excellent adhesion, high content of C and H elements [20], [21], [22].

In CSP systems, aluminum has an important role in condensed combustion systems. Aluminum powder (5-20 µm) is usually added to solid propellants to increase the specific impulse of the engine due to its high energy density. Aluminum is an energetic material that is suitable for solid propellant applications because of its abundant availability, low cost, low oxygen consumption, and strong exothermic oxidation [23].

The characteristics of aluminum metal fuel with a high exothermic heat of combustion (7.4 kcal/g) and excellent thermal conductivity values can potentially increase the combustion rate [24], [25]. This shows that the AP/Al combustion rate produced is very high. Aluminum particles are able to react not only with free oxygen resulting from the decomposition of oxidizers but are also able to react with inert decomposition gas products

and add more heat to the combustion process [26], [27].

Based on the background description that has been explained, in this study a comparative analysis of propellant combustion speed was carried out with variations in AP/Al/Epoxy materials and pressure variations. The best performance produced is a propellant composition that has a fast combustion rate and high pressure.

2. RESEARCH SIGNIFICANCE

The contribution of this research is in developing more efficient and safer propellants by analyzing material variations (ammonium perchlorate/aluminum/epoxy) and pressure on propellant combustion speed. Suboptimal combustion rates can reduce rocket performance and increase safety risks, so this research is important for producing better propellants in military and aerospace applications. Through comparative analysis of material and pressure variations, this research provides deep insight into the relationship between pressure and combustion rate, which can be used to optimize future propellant designs, improve energy efficiency, and ensure operational safety of rockets.

3. RESEARCH METHODS

The materials used in this research were propellant, nickel wire and tin. The tools used in this research are propellant velocity measuring instruments, compressors, cameras and electric current sources.

Preparation of tools and materials used in the process of making test samples, starting with making propellant consisting of ammonium perchlorate, aluminum powder, epoxy, stirring tools and others. As well as weighing ingredients according to percentages. The percentage composition of the propellant is shown in Table 1.

Table 1. Propellant Composition Planning

No	Composition	Total mass of propellant	Percentage					
			Ammonium Perchlorate		Aluminum		Epoxy	
		grams	%	grams	%	grams	%	grams
1	A	50	56	28	16	8	28	14
2	B	50	54	27	20	10	26	13
3	C	50	52	26	24	12	24	12

The process of making AP/Al/Epoxy solid propellant is by adding the epoxy material into the stirrer until it is evenly distributed, adding the Aluminum Powder into the stirrer, then stirring the mixture until it is even, adding the Ammonium Perchlorate with the epoxy mixture. After the mixture is even, put it in the mold until it dries. After the propellant dries. can be taken from the mold. Next is the process of forming the test sample, by cutting the propellant according to the size of the sample to be tested, namely 3 cm long, 0.5 cm wide and 0.5 cm high. Propellant's rapid creep experimental setup is shown in Figure 1.

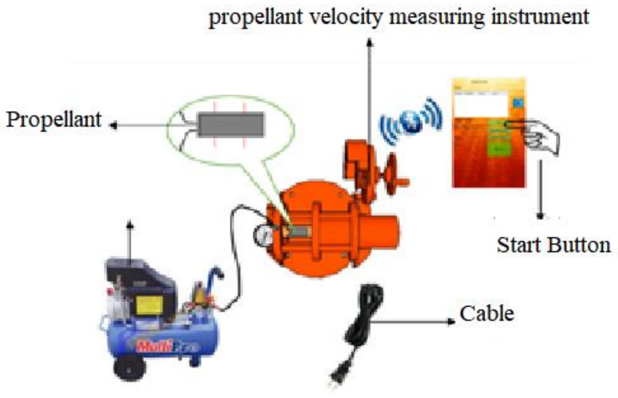

Fig. 1. Experimental setup

The first steps of the test procedure are preparing the tools and materials used in the test, installing and placing the propellant which has nickel and tin wire installed in the combustion place. The second step, install the nickel and tin wire on the kiln holder. The third step, close the test tube, then lower the cover and tighten it. The fourth step, provides air pressure from the compressor according to the pressure variation that will be tested, namely atmospheric pressure, pressure 1 – 5 bar. The fifth step, connect the hardware component cables to the power source. Sixth step Activate the igniter combustion switch in the software. In its application, the propellant combustion speed measurement tool is used to determine the combustion speed when a certain pressure is applied. If combustion has occurred, the first lead that is passed will activate the timer to start the combustion time. After the burning hits the second tin, the burning time will automatically stop. While changes in pressure over time are used by the camera to obtain video data. Based on data from video analysis of pressure changes over time, data on the speed of combustion was obtained.

4. RESULT AND DISCUSSION

Data on propellant testing results with variations in material and pressure over time are shown in Figures 9, 10 and 11.

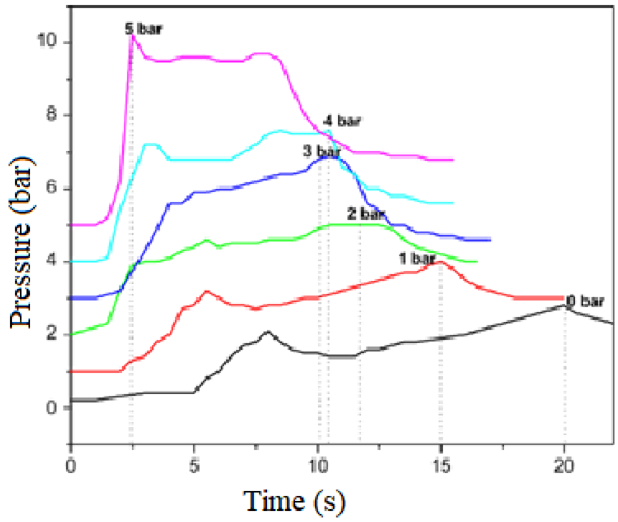

Fig. 9. Propellant A combustion time and pressure.

Pressure changes from burning propellant A during combustion time (Figure 9). We can see that the pressure increase during combustion tends to be linear to the propellant combustion speed. Apart from that, at atmospheric pressure it produces a propagation speed of 0.1182 cm/s as the lowest value and at an initial pressure of 5 bar the propagation speed is 0.3015 cm/s as the highest value. This is possible because the propellant is mixed homogeneously, there are no voids in the propellant. So that when the combustion takes place, the combustion takes place in a cigarrette burning manner or evenly. Meanwhile, the calculation using the regression approach for propellant A produces a value of n (pressure constant) of 0.53, which indicates that the propellant is good because it is still within the combustion speed index of 0.3 – 0.6.

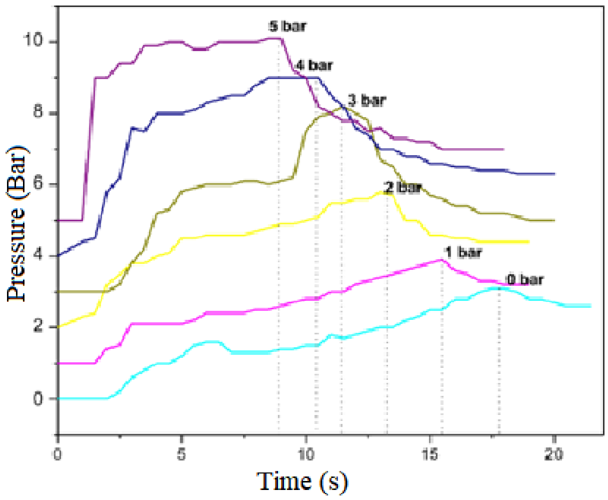

Fig.10. Propellant B combustion time and pressure.

In propellant B shown in Figure 10, there is a significant pressure jump at the end of combustion at a pressure of 3 bar. With the lowest propagation speed value of 0.1300 cm/s at an initial pressure of 1 bar, and the highest 0.2929 cm/s at an initial pressure of 5 bar. Then for the value n = 0.44. A pressure jump can occur due to several things, one of which could be because there is a cavity in the propellant sample. So that when combustion hits the cavity, the combustion area becomes larger, the pressure becomes higher and the speed of combustion also increases.

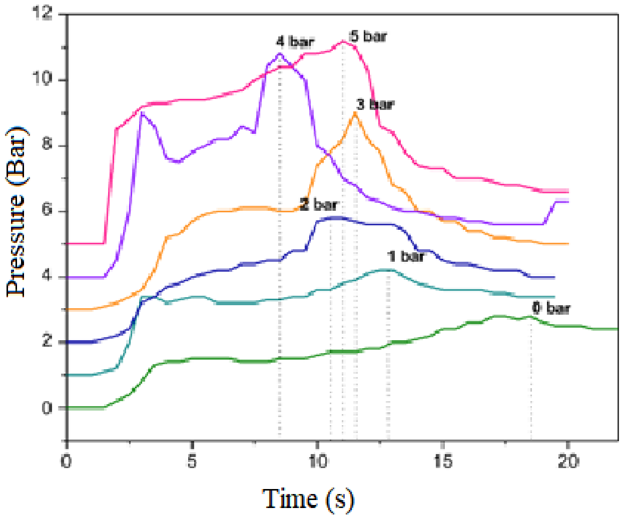

Fig. 11. Propellant C Combustion Time and Pressure.

In propellant C shown in Figure 11, there is also a pressure jump at the initial combustion pressure of 2 bar, 3 bar and 4 bar. With the lowest propagation speed value of 0.1348 cm/s at an initial pressure of 0, and the highest 0.2829 cm/s at an initial pressure of 5 bar. Then for the value n = 0.47. The occurrence of pressure jumps in several samples shows that the composition contains porosity.The results of the combustion speed of each propellant can be seen in Figure 12.

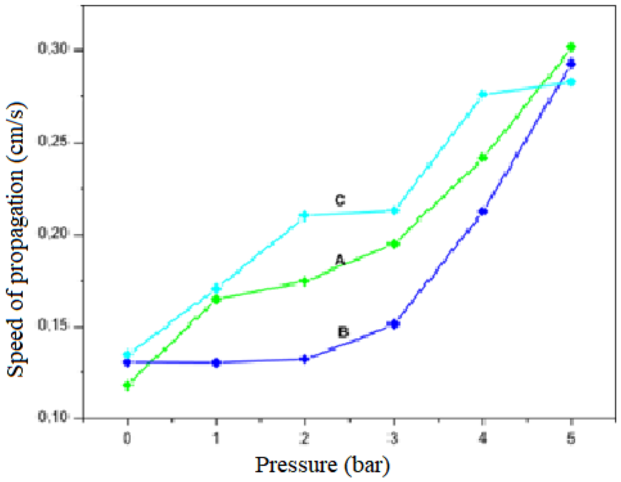

Fig.12. The Correlation of the speed of propagation of ABC Propellant against pressure variations.

Figure 12 and Figure 13 show that for propellant A, the lowest propellant combustion mass flow rate was 0.301 gr/s at atmospheric pressure and the highest was 0.797 gr/s at an initial pressure of 5 bar. The combustion mass flow rate that occurs tends to be the same at initial pressures of 2 bar and 3 bar. This is possible because the density or level of density is influenced by different cross-sectional areas. The results of the propellant combustion mass flow rate can be seen in Figure 13**.**

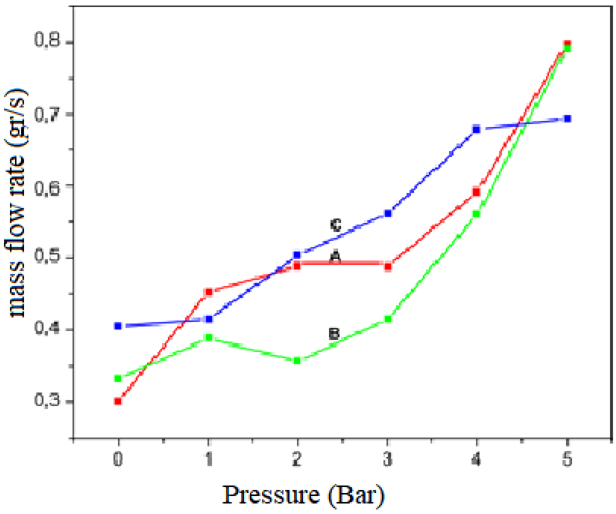

Fig. 13. Mass flow rate of propellant ABC against pressure.

Figures 12 and 13, propellant B obtained the lowest propellant combustion mass flow rate of 0.332 gr/s at atmospheric pressure and the highest 0.791 gr/s at an initial pressure of 5 bar. There was a decrease in the combustion flow rate at an initial pressure of 2 bar. This is because other factors such as density level, cross-sectional area, and the resulting combustion speed tend to be different.

Judging from Figures 12 and 13, propellant C obtained the lowest propellant combustion mass flow rate of 0.405 gr/s at atmospheric pressure and the highest 0.694 gr/s at an initial pressure of 5 bar. The higher the density level, the greater the resulting mass flow rate. And another influencing factor is the occurrence of porosity.

The burning rate of solid rocket propellant is expressed as a regression of the burning surface [28], [29]. The combustion rate can be increased by increasing the combustion temperature and/or combustion pressure [30], [31]. Combustion temperature and pressure can be controlled by integrating various potential AP oxidizers and/or aluminum active metal fuels. These energetic additives have the potential to induce exothermic reactions in the induction zone, reducing its thickness, and thereby increasing the combustion rate [32].

To determine the internal pressure of a rocket motor, it is necessary to determine the geometry of the propellant core because the internal pressure of the motor depends on the combustion area. When solid fuel burns, the combustion area changes. Therefore, to estimate the pressure-time of the motor, each combustion step is needed in the combustion area. The analysis carried out to determine the burning area at each stage of combustion is called burn back analysis [33].

Star-shaped structures are generally preferred to represent solid-fuel rocket motor cores although other geometric shapes exist. In star-shaped solid fuels, the burning surface area remains constant at approximately ±15% during combustion. The remaining burning surface area helps the burning rate run smoothly, allowing the rocket to fly more stably.

Star-shaped propellant [34].

The burning rate of solid rocket propellant is a function of the propellant content. The propellant mixture content directly affects the combustion rate. Factors that can change the burning rate are the addition of a catalyst or burning rate, reducing the particle size of the oxidizer, increasing the percentage of the oxidizing agent, increasing the amount of binder or oxidizing agent to increase the burning rate, and adding metal rods or metal fibers to the fuel [35]. The influence of motor production conditions on the combustion rate, apart from the chemical composition of the solid propellant, is the combustion chamber pressure, the initial temperature of the propellant before combustion, the temperature of the burning gas, the velocity of the gas flow parallel to the combustion surface, the movement of the motor (acceleration and regression of turbulence in the core), and the rate of Combustion of solid rocket propellant behaves differently depending on various factors [36].

Increasing the pressure in the combustion chamber is one of the most important factors that increases the combustion rate. As shown in Figure 16, as the combustion chamber pressure increases, the flame profile varies; the size of the fire decreases and burns faster [37]. The combustion behavior and rate of solid rocket propellants vary at different pressures. The combustion rate increases as the combustion chamber pressure increases [38]**.**

5. CONCLUSION

Based on the results of the research, the relationship between the air pressure provided is directly proportional to the combustion speed and the mass flow rate of the propellant. The greater the pressure applied, the higher the combustion speed and propellant mass flow rate. The best performance is found in propellant B with a value of $n = 0.44$. A constant value close to 0 (zero) indicates a much more sensitive level of propellant sensitivity. The resulting mass flow rate at an initial atmospheric pressure of 0.332 gr/s and at an initial pressure of 5 bar is 0.791 gr/s.

6. ACKNOWLEDGEMENTS

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