Study of Burning Rate Characteristics of Composite Propellant Based on Nitrated Hydroxyl Terminated Polybutadiene (NHTPB) Binder

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***Abstract*—** One of the parameters that can be utilized to determine the performance and internal ballistic properties of rocket propellants is the burning rate value. Based on previous research, it's known that the binder based on NHTPB (Nitrated Hydroxyl Terminated Polybutadiene) has the potential to increase the energetic properties of composite propellants. This study aims to analyze the characteristics of the internal ballistic properties of the burning rate of rocket composite propellants produced by using a binder based on NHTPB as an effort to support the development of rocket propellants technology in Indonesia. Literature studies was conducted by reviewing previous research journals. Based on several research, it shows that the NHTPB Binder can increase the burning rate of composite propellants by about 10-30%. The burning rate value of composite propellants produced is 10-13 mm/s. This burning rate value exceeds the standard propellant burning rate and propellant currently available in ORPA-BRIN (Rocket Technology Research Center) is >0.7 mm/s. The addition of an energetic plasticizer component also plays a role in influencing the increase in the burning rate. The NHTPB energetic binder can be an alternative in developing solid composite propellant manufacturing technology in the future as an effort to rocket propellants technology in Indonesia.

***Keywords*—** Nitrated Hydroxyl Terminated Polybutadiene, Binder, Burning Rate, Composite Propellant.

I. INTRODUCTION

The main component of composite propellants as a rocket fuel consisting is fuel, binder, oxidizer and additive components (metal fuel, adhesive agent, and plasticizer) which are useful for obtaining characteristic properties and improving the quality of a propellant [16]. In its application in aerospace technology, solid composite propellants are often used as fuel in rockets for military purposes [18]. In the context of mastering rocket propellant technology in Indonesia, propellant development at ORPA-BRIN (Rocket Technology Research Center) to use composite propellants based on AP/HTPB/Al, its Ammonium Perchlorate as an oxidizing agent, Hydroxyl Terminated Polybutadiene as a binder, and Aluminum as a fuel which has a high energy level [1].

An energetic binder is a polymer that is bonded together between an explosive material and a plasticizer into a strong and flexible three-dimensional component [7]. HTPB (Hydroxyl Terminated Polybutadiene) is the most widely used prepolymer as a solid composite propellant binder (about 10-15% by mass of the propellant composition) [17]. HTPB is often used as a binder in solid composite propellants because of its high solid loading characteristics compared to other binders, which is 89-90% [13].

This HTPB compound is non-energetic and has a low energy level, so efforts are being made to obtain a binder with high energetic properties by adding a nitro group to the HTPB compound through the nitration process to form a new compound Nitrated Hydroxyl Terminated Polybutadiene (NHTPB) which is more energetic and remain stable [1]. So many energetic binders have been found that produce good energy properties, but lack mechanical properties where there are difficulties with high solid loading and difficulty adapting to other components [17]. Thus, with its high stability properties, NHTPB binders are relatively easy to combine with other active ingredients [12].

Nitrated Hydroxyl Terminated Polybutadiene (NHTPB) is the most studied binder recently in the development of rocket propellant. NHTPB can be combined with other compounds to increase the effectiveness of the combustion rate value by 10-30% and the combustion temperature by -54°C [3]. In solid rockets, NHTPB is a very stable fuel and relatively easy to combine with other active ingredients.

To produce the energetic compound NHTPB binder, a nitration process is needed. The nitration process by substitution 10% of the double bonds into ester dinitrate groups. The NHTPB produced will provide energy effects and good mechanical properties [9]. Abdillah *et al.* (2018) was conducted a study about the most effective and optimal NHTPB synthesis process is to use sodium nitrite which is cooled at low temperature (0°C). Figure 1 shows the NHTPB preparation.

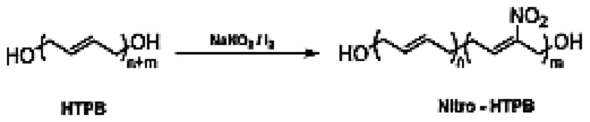

Figure 1: *Preparation of Nitrated Hydroxyl Terminated Polybutadiene (NHTPB) [17].*

One of the parameters that can be utilized to determine the performance and ballistic properties of a rocket propellant is to know the burning rate of the resulting propellant. The rate of combustion is used to determine how much thrust or thrust the propellant generates. Table 1 shows some characteristics of propellants in ORPA-BRIN using HTPB binders. It shows that the burning rate of standard propellant and propellant currently used in ORPA-BRIN is >0.7 mm/s [21].

Table 1: *Characteristics of Composite Propellants in ORPA-BRIN [21].*

Propellant Characteristics	ORPA-BRIN Propellant (AP/HTPB/Al)
Isp (s)	220
R (mm/s)	>0.7
Solid Content (%)	85
AP/HTPB/Al (%w/w)	80/15/5
AP Trimodal (mesh)	400/200/100
Density (gr/cm^3)	1.67
Homogeneity (%)	98

There are several recent studies related to the use of NHTPB binders to obtain higher energy from the propellant performance results. Based on several research, it's known that the NHTPB based binder has the potential to increase the energetic properties of solid composite propellants.

Therefore, it's necessary to do further research on the analysis of the characteristics of the ballistic properties of the burning rate of composite propellants produced based on NHTPB binder compound in an effort to develop rocket propellant technology in Indonesia.

This study was designed as an effort to support the independence of domestic propellant technology by increasing the performance of solid composite propellants by looking at the burning rate value using a NHTPB based binder.

II. METHODOLOGY

The research was conducted by applying qualitative research methodology. Literature studies was applied referring to the characteristics of the ballistic properties of the burning rate value of a composite propellants based on a NHTPB binder. Literature studies was conducted by reviewing previous research journals and then reviewing and discussing them. The results and discussion were obtained by collecting various data from references to the results of relevant journal reviews. Furthermore, the results of the burning rate characteristics of propellant based on NHTPB binder from several previous research journals can be compared to produce comprehensive and useful data and information that can be used in future research and development of propellant technology. During the last 10 years, there have been several journals related to composite propellants based on NHTPB binder. From this publication, there are characteristics regarding the burning rate value of composite propellants based on NHTPB binder produced Abdullah *et al.* (2014); Florczak *et al.* (2015); Abusaidi *et al.* (2017); Qarabagh *et al.* (2018); Azazy *et al.* (2021).

III. RESULT AND DISCUSSION

Characteristic parameters of solid composite propellants can be evaluated by value of the burning rate which represents the internal ballistic properties of a solid composite propellant produced. Furthermore, there is a specific impulse value (Isp) which indicates the energy of the propellant, the viscoelastic value of the propellant, mechanical properties such as hardness and strength tests, and physical properties such as homogeneity, cracking, and porosity [22].

The burning rate is calculated so that it can be seen how much thrust or thrust is generated by the solid composite propellant produced [18]. The burning rate value of standard propellant is >0.7 mm/s [21]. To determine the burning rate value, the equation $r = aP^n$ can be used, where r is the measurement of the burning rate (mm/s), a is the burning rate consistent esteem decided by linear regression analysis of the information within the log-log diagram (3.28), P is the pressure (MPa) and n is the pressure exponent (0.51) [2]. Based on the several research in Table 2, shows the result of characterization of the burning rate of composite propellants based on NHTPB binder.

Table 2: *Characterization of the Burning Rate of Composite Propellants Based on NHTPB*

Author (Year)	R (mm/s) with HTPB	R (mm/s) with NHTPB
Abdullah *et al.* (2014)	7.51	11.03
Florczak *et al.* (2015)	-	10.00
Abusaidi *et al.* (2017)	7.75	13.71
Qarabagh *et al.* (2018)	10.15	11.04
Azazy *et al.* (2021)	9.86	10.12

From the data obtained in Table 2, its shows that the propellant based on the NHTPB binder affects the internal ballistic and mechanical properties of a solid composite propellant produced. The value of the resulting combustion rate is greater than the use of an HTPB binder. Thus, it's proven that the NHTPB Binder can increase the burning rate of composite propellants by about 10-30%. In addition, the propellant with NHTPB produced a higher density value (1.92 g/cm^3) compared to the propellant with HTPB (1.79 g/cm^3) [3].

The results of the study suggest in future research to improve the performance of the propellant by using an NHTPB binder. It's known that the propellant composition can also affect the result of burning rate value. Figure 2 shows the burning rate value to the composite propellants composition of NHTPB.

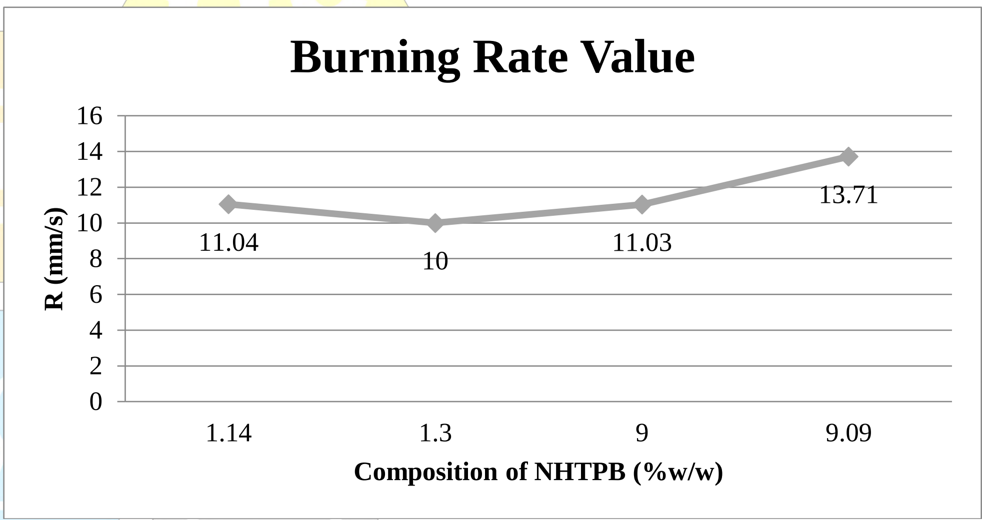

Figure 2: *Burning Rate Value of Composite Propellants Composition of NHTPB*

Figure 2 shows that the composition of the composite propellant based on NHTPB is 9.09%-w/w, indicating the highest burning rate value for the propellant, which is 13.71 mm/s [3]. Therefore, the addition of a small amount of NHTPB of <2% can affect ballistic properties and energy of the propellants, which can increase the calorific value of the resulting propellant by 6632 J/g [11]. Various factors such as oxidizing agents and fuel composition have been known to play an important role in changing the burning rate. In its application as a propellant, a low viscosity value will produce a propellant with high combustion energy, high thrust, and quickly exhausted, and vice versa [15].

Furthermore, the addition of additives an energetic plasticizer can also affect the increase in the burning rate resulting from solid composite propellants. As in the research that has been done Abdullah *et al.* (2014) and Abusaidi *et al.* (2017) with the addition of the energetic plasticizer Bu-NENA which can increase the burning rate value of the composite propellants.

Table 3 shows the difference in the characteristics of the burning rate value based on NHTPB and additive Bu-NENA plasticizer and without using an energetic plasticizer

Table 3: *The Characteristics of The Burning Rate Based on Plasticizer and Without Plasticizer*

Author (Year)	R (mm/s) without Plasticizer	R (mm/s) with Bu-NENA
Abdullah *et al.* (2014)	8.44	11.03
Abusaidi *et al.* (2017)	7.75	13.71

Based on Table 3, Ashrafi *et al*., (2017) also stated that the energetic plasticizer of NPB (Nitropolybutadiene) can bind the NHTPB binder to produce composite propellants with better mechanical properties than HTPB/DOA. This is in line with research which states that the NHTPB binder has been shown to be able to be combined with a large number of energetic plasticizers [9]. The use of NHTPB with the energetic plasticizer Bu-NENA can improve the mechanical properties, by producing a higher density value than the propellant without plasticizer.

NHTPB compounds have the advantages of good mechanical properties as well as higher energy and are more stable. The addition of a small amount of NHTPB can increase the calorific value of the resulting propellant, which is 6632 J/g [11], and produces a higher density value (1.92 g/cm^3) compared to propellant with HTPB (1.79 g/cm^3) [3]. Some propellants containing 10% of NHTPB can increase the propellant energy by 8% without compromising on the mechanical properties and operating conditions. Due to its high stability, the NHTPB binder does not require special handling in the propellant manufacturing process [20].

To increasing propellant energy, it can be done by observing two stages, the use of energetic compounds and refinement of the technology process [22]. The energetic material developed is a stable material. Studies on the use of energetic binder compounds lead to the use of energetic NHTPB material which is relatively stable and has good mechanical properties compared to other energetic binder materials.

Previous studies show that the NHTPB binder can be an alternative to replace the HTPB binder in the manufacture of rocket composite propellants. It's proven that the propellant based on the NHTPB Binder produced has a high burning rate value that exceeds the standard propellant burning rate value. The standard burning rate value of solid composite propellant and propellant in ORPA-BRIN is >0.7 mm/s [21]. In this case, it's highly recommended to use a NHTPB-based binder to be further researched and developed for rocket propellant technology in the future.

IV. CONCLUSION

The characteristic results from the literature study provide information that the NHTPB binder can increase the burning rate of a solid composite propellant by about 10-30%. The burning rate value of the composite propellants produced is 10-13 mm/s. This burning rate value exceeds the standard propellant burning rate and propellant currently available in ORPA-BRIN (Rocket Technology Research Center) is >0.7 mm/s.

The addition of an energetic plasticizer component also plays a role in influencing the increase in the burning rate. So that in the future, the NHTPB energetic binder can be an alternative in the development of solid composite propellant manufacturing technology as an effort to master rocket propellant technology in Indonesia.

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