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Research paper

Studies on the High Performance Characteristics of an Aluminized Ammonium Perchlorate Composite Solid Propellant Based on Nitrile Butadiene Rubber

Sudhir Singh^{1,*}, Sidharth Raveendran¹,
Dhirendra R. Kshirsagar¹, Manoj Gupta¹, Chetan Bhongale²

¹ *High Energy Material Research Laboratory, Sutarwadi,
Pune 411021, India*

² *Defence Institute of Advanced Technology, Deemed University,
Pune 411025, India*

*E-mail: sudhirss007@gmail.com

ORCID information

Sudhir S.: 0000-0002-3901-2733

Abstract: In the present study, a high performance composite solid propellant formulation was prepared based on nitrile butadiene rubber (NBR) and dibutyl phthalate (DBP) plasticizer, which has a longer pot life and high density specific impulse. The developed cost effective novel binder system was prepared with readily available raw materials (NBR and DBP). The formulation of the composition was performed by varying the content of the NBR/DBP binder in the range of 14-20%. The rocket performance characteristics were determined theoretically using PROPEP and compared with those of an HTPB based propellant. The rheological, mechanical, physical, ballistic and thermal properties of the NBR/DBP propellant were studied and compared with literature data for similar compositions based on an HTPB/dioctyl adipate (DOA) binder. The yield stress was determined by spreadibility measurements, and indicated the superiority of this binder based propellant over existing composite propellants. It was concluded that following decreasing the content of the NBR/DBP binder in the propellant from 20 to 14%:

- in the range 58.83-78.45 bar (5.883-7.845 MPa), the pressure index increased from 0.159 to 0.371,
- at 68.64 bar (6.864 MPa), the burning rate increased from 4.10 to 6.54 mm/s, but the theoretical specific impulse value did not change significantly (258.0-259.8 s),
- the tensile strength and E-modulus increased from 6.03 to 9.88 (0.591-0.969) to and from 18.00 to 75.00 kgf/cm² (1.765 to 7.355 MPa), respectively.

Moreover, a DSC and TGA study indicated a lower decomposition temperature for the NBR/DBP propellant compared to the HTPB propellant. The NBR/DBP propellant exhibited a pot life more than double that of a conventional HTPB/DOA based propellant.

Keywords: composite solid propellant, dibutyl phthalate, high density specific impulse, nitrile butadiene rubber, pot life, spreadability, yield stress

Nomenclature

DBP	Dibutyl phthalate
DOA	Dioctyl adipate
HTPB propellant	Propellant with a binder based on hydroxyl terminated polybutadiene (HTPB)
HTPB/DOA propellant	Propellant with a binder based on HTPB + DOA
NBR	Nitrile butadiene rubber
NBR/DBP propellant	Propellant with a binder based on NBR + DBP

1 Introduction

Composite propellants are the main source of propulsion for rockets and missiles. A composite propellant is a mixture of ammonium perchlorate (AP) as an oxidizer, aluminum powder as a primary fuel, ballistic modifiers and certain process aids dispersed in the polymer binder system [1, 2]. The properties of a propellant are affected by the binder system in the propellant formulation and can be varied by changes in the binder content [3, 4]. The polymer binder system is a very important constituent of a composite propellant formulation. It becomes adsorbed and adheres to the filler by a wetting process. In the initial stages of the development of composite propellants, a number of polymers were used as fuel binders [4]. The binders employed in the initial stages of the development of rocketry are now of historical importance. A polymer to be used as a binder for composite rocket propellants should possess a number of desirable properties, such as compatibility with the oxidizer, fuel and the other ingredients of the propellant.

Polybutadiene acrylonitrile (PBAN), hydroxy terminated polybutadiene (HTPB) and carboxy terminated polybutadiene (CTPB) polymer binder systems have been investigated for the processing of composite propellant formulations [5-8]. HTPB binder is cured with di-isocyanate curing agents, which are extremely toxic and carcinogenic in nature, and exhibits a comparatively short pot life [9]. HTPB is immiscible with energetic plasticizers, which further restricts enhancement of the energy output of a propellant. Furthermore, rubber based binders, *viz* isoprene, butyl and nitrile butadiene rubber (NBR) polymeric binders, are also used for the processing of composite solid propellant compositions due to their low glass transition temperature ($<-80\text{ }^{\circ}\text{C}$) characteristics, high solid loading processing capability, low cost, longer pot life and ready availability [10]. NBR can be plasticized with a variety of plasticizers due to its variable polarity on account of different acrylonitrile (ACN) content. The ACN content controls the solvent resistance, oil resistance, abrasion resistance, mechanical properties and glass transition temperature of the NBR polymer. NBR is an unsaturated copolymer of ACN and butadiene. The general structure of NBR is shown in Figure 1.

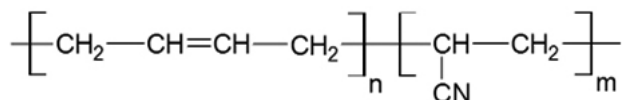


Figure 1. General structure of NBR (m and n are the ACN and butadiene contents, respectively)

NBR can be plasticized with energetic and non-energetic polar plasticizers or a combination thereof. The major factors determining the solvation of polymers by plasticizers are the chemical structure and polarity of the molecules. Polar plasticizers with polar groups can be compatible with non-polar polymers, but only when the content of the polar groups in the plasticizer is sufficiently small, and the compatibility decreases as the polar group content increases in the plasticizer [9]. Polymers of average polarity (*e.g.* PVC, PC and butadiene-acrylonitrile copolymers) have solubility parameters in the range of 17 to 20 $\text{J}^{0.5}\text{cm}^{-1.5}$ [11-13]. Polar plasticizers with proton-accepting characteristics (esters, ethers, and nitriles) are the most useful for plasticizing NBR [11]. In the present research, NBR/dibutyl phthalate (DBP) was selected as the binder material. The selection of DBP as the plasticizer was based on the chemical compatibility between NBR and DBP due to their similar chemical nature, which is explained by the solubility parameter. The solubility parameter (δ) of DBP is 18.9 and of NBR is 18.8 $\text{J}^{0.5}\text{cm}^{-1.5}$ [14]. The difference

between the solubility parameters ($\Delta\delta$) of NBR and DBP is $0.1 \text{ J}^{0.5} \text{ cm}^{-1.5}$. The small difference between δ_s and δ_p results in smaller ΔH_{mix} and ΔG_{mix} and indicates better solubility [15], hence it creates a miscible and compatible system. DBP is readily available in the market and the commercially most used plasticizer for NBR. Hence the initial study involved plasticizing NBR with DBP [11]. Keeping in view the advantages of NBR, a novel binder based on NBR and DBP was prepared for evaluation in the propellant composition. A systematic study was carried out to evaluate the effect of the binder on the composite propellant formulation. The challenges of an HTPB based binder motivated the authors to investigate the NBR/DBP binder for propellant applications, especially in view of a desirable longer pot life and a non-hazardous binder system.

2 Materials

AP was used as a blend of 300 and 50 μm particle sizes. Coarse AP powder was procured from M/s Pandian Chemicals Ltd. (Cuddalore, India). The fine AP of 50 μm was prepared by size reduction using a grinding instrument air classifying mill. NBR was procured from Abhang Organics (Pune, India) and the vulcanising additive was procured from Indian Adhesives and Glues (Pune, India). M/s Metal Powder Company (Madurai, India) supplied the aluminum powder of particle size 6 μm . Analytical reagent (AR) grade chemicals such as DBP were procured from M/s Sigma Aldrich.

3 Preparation of the binder and composite propellant

The NBR/DBP based binder was prepared from 15% NBR plasticized with 85% DBP. The experimental mixing of the composite propellant with 20 to 14% binder content was carried out at an 8 kg batch level in a vertical planetary mixer. The binder ($17 \pm 3\%$) was charged to the vertical planetary mixer (capacity 15 L) and mixed well for 30 min, followed by mixing under vacuum for a further 30 min to remove entrapped air. Al powder (18% ; $\sim 6 \mu\text{m}$) was added and mixed carefully for 30 min. Subsequently, AP ($65 \pm 3\%$; particle sizes 300 and 50 μm) was added and mixed homogeneously. The temperature of the overall mixing was maintained at $50 \pm 2 \text{ }^\circ\text{C}$. After complete addition of the solid ingredients, the composition was further mixed under vacuum for 1 h and a vulcanizing additive was added at $50 \text{ }^\circ\text{C}$. The ratio of vulcanizing additives and binder was constant for all compositions. The propellant compositions

were cast, by the vacuum gravity method, into moulds of 115 mm inner diameter and the moulds were cured at 60 °C for 15 days in a water jacketed oven [5]. The processed propellant compositions were designated as PBC1, PBC2, PBC3 and PBC4. In all of the compositions, AP has been replaced with binder. The details of the compositions are listed in Table 1. HTPB binder data is taken from literature and theoretical predictions [8, 16-20].

Table 1. Formulation of propellant compositions by varying binder content

Propellant	Component [wt.%]			
	NBR/DBP binder	HTPB/DOA binder	AP (coarse and fine)	Al (6 μm)
PBC1	20	–	62	18.0
HC1	–	20		
PBC2	18	–	64	
HC2	–	18		
PBC3	16	–	66	
HC3	–	16		
PBC4	14	–	68	
HC4	–	14		

4 Test Methods

A particle size analyzer (CILAS model 1064 L) was used to determine the particle size distribution of AP and Al, based on the laser scattering technique, by dispersion of 0.1 g samples in 50 mL of a mixture of carbon tetrachloride and isopropyl alcohol in a volume ratio of 60:40.

The rheological properties were determined using a rheometer Anton Parr MCR101 at 27 °C. The viscosity of the binder and propellant slurry was measured using a Brookfield dial type viscometer (model HBT) by inserting a T-C spindle at a rotating speed of 2.5 rpm at a programmed temperature into a 500 mL capacity container of about 75 mm diameter and 100 mm height, in a circulating water bath which could maintain the desired temperature with an accuracy of ±0.1 °C.

Measurement of the yield stress of the NBR/AP/Al based propellant composition was performed at a constant temperature using a slump test or spreadability measurement using a specially designed instrument [16, 17]. A Hounsfield universal testing machine (UTM) was used to determine mechanical properties, such as tensile strength (TS), E-modulus (E-mod) and % elongation (% E) using dumbbells, conforming to ASTM-D-638 type IV,

at a cross head speed of 50 mm/min at ambient temperature. The width and thickness of the specimens were measured. The specimens were placed in the appropriate grips of the testing machine and aligned properly. The specimen was stretched at the rate of 50 mm/min. The recorded load/extension measurement curves were used to calculate the TS, % E and E-mod.

The hardness of the propellant samples was measured using a shore A dial gauge durometer by the indentation method. Five readings were taken on a uniform surface of the propellant sample and the average value is reported.

The density of propellant samples cut into pieces of 25×25×25 mm (±0.1 mm) was determined using a helium gas pycnometer Thermo Scientific (Pycnometric EVO). The sample vessel was filled up to 60-70% of its volume with the sample, was placed in the sample chamber of the instrument and the density of the sample was measured.

A Parr isoperibol bomb calorimeter 6220 was used to evaluate the calorimetric value of propellant samples under a N₂ atmosphere. The calorimetric value was found by taking 1 g of propellant sample inside the crucible and heating to 30 °C.

The acoustic emission technique was used for the determination of the burning rate of cured composite solid propellant samples in an inert atmosphere (N₂) at different pressures in a 750 mL stainless steel bomb. The bomb was fitted with a lid with a panel for holding the propellant strand and a piezoelectric transducer [18]. The propellant sample (dimensions 150×6×6 mm) were made in the form of strands and ignited from one end with the help of a Nichrome wire. The rapid release of energy on combustion of the propellant produces acoustic signals. The acoustic pulse from propellant strand burning was recorded on an oscilloscope. The length of the strand and the duration of the acoustic pulse gives the burning rate of the composite solid propellant. An error of ±0.2 mm/s is expected in the measured burning rate on account of manual measurement errors.

The thermal decomposition of the propellant was studied using simultaneous DSC-TGA analysis, Q-600 instrument (TA, USA), with a nitrogen flow rate of 100 mL/min and a heating rate of 10 °C/min.

5 Results and Discussion

5.1 Theoretical performance of the propellant compositions

The theoretical performance of NBR/DBP binder based propellant compositions was calculated by ProPEP3 software and compared with HTPB

based propellant compositions. Two important performance parameters used for characterizing propellants are specific impulse and density specific impulse (density \times specific impulse). Lower stage motors of missile are preferably configured with higher density specific impulse propellants and the upper stages of missiles are configured with higher specific impulse propellants. NBR/DBP binder based propellants have advantages over the corresponding HTPB based compositions, as illustrated in Table 2. The flame temperature and specific impulse increase from PBC1 to PBC4, probably due to an improvement in the oxygen balance. There is a gain of 2 s in the specific impulse by replacing 6% of the binder with AP for the NBR/DBP compositions, while there is a gain of 12 s in the specific impulse in the case of the HTPB/DOA binder based compositions. This can be explained by the higher oxygen balance of the NBR/DBP based binder compared to the HTPB/DOA based binder. As shown in Figure 2, the higher oxygen balance of the novel binder contributes to the higher oxygen balance of the propellant, the higher flame temperature of the propellant and consequently to a higher specific impulse; up to 18% of binder content as shown in Figure 2.

Table 2. Theoretical performance of NBR/DBP and HTPB/DOA binder based compositions at 68.64 bar (6.864 MPa)

Composition	Density [kg/m ³]	Flame temperature [K]	Specific impulse [s]
PBC1	1748	3036	258.0
PBC2	1776	3133	258.3
PBC3	1802	3300	259.8
PBC4	1836	3370	259.8
HC1	1662	2472	249.7
HC2	1691	2759	256.9
HC3	1726	2960	260.1
HC4	1762	3132	261.6

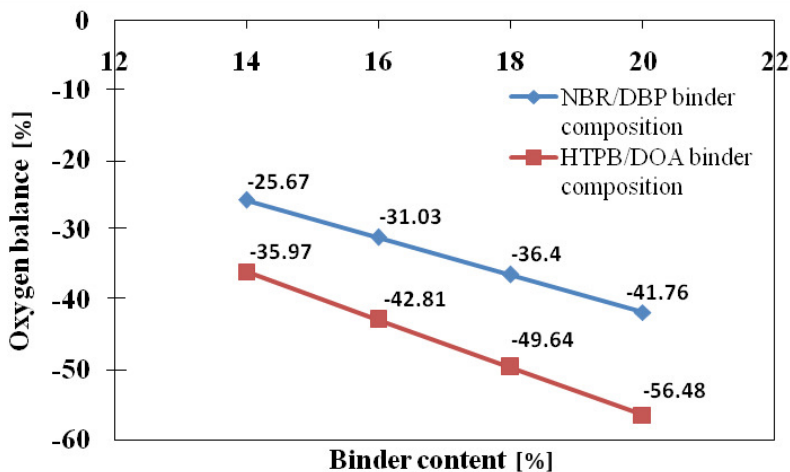


Figure 2. Theoretical oxygen balance of NBR/DBP and HTPB binder based compositions

The specific impulses of the PBC1 and PBC2 compositions are higher than the corresponding HTPB based compositions (HC1 and HC2), and the PBC3 and PBC4 compositions exhibit lower specific impulses than the corresponding HTPB based compositions (HC3 and HC4). However the PBC3 and PBC4 compositions exhibit higher density specific impulses (2-4%) than the HTPB binder based propellants (HC1, HC2, HC3 and HC4) due to the higher density of the NBR/DBP binder and consequently the propellant, as shown in Figure 3. The theoretical performance predictions show that the novel binder based compositions can achieve better performance compared to the HTPB binder based propellants, especially for the lower stage motors of missiles.

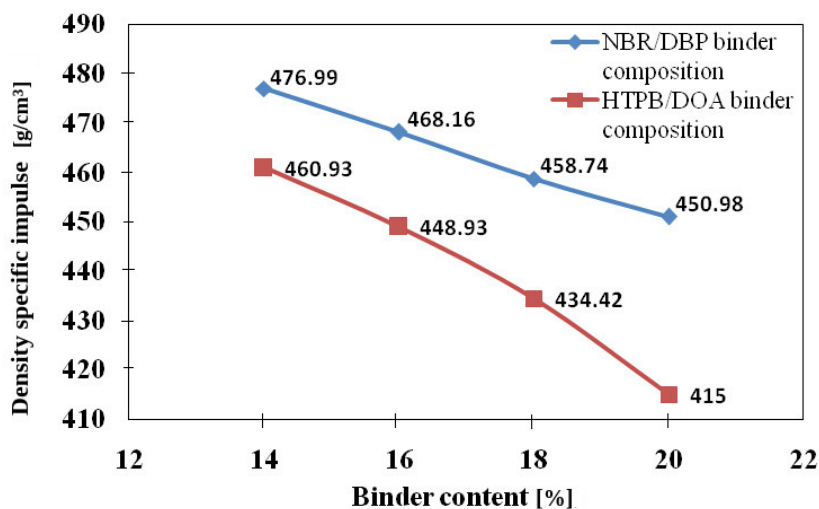


Figure 3. Theoretical density specific impulse of NBR/DBP and HTPB/DOA binder based compositions

5.2 Rheology

The rheological characterization of propellant suspensions plays very important role as it affects important processing steps, such as mixing and casting. In order to maximize the performance of a propellant, the solid loading is usually close to the maximum packing fraction (volumetric loading >75%). The suspension of solid particles in the binder exhibits complex rheological behaviour, which is affected by concentration, size distribution and shape of the particles, as well as the nature of the binder and plasticizer [16, 17, 19]. The rheological properties of the propellant compositions were studied on a rheometer while varying the binder content from 20 to 14%. The results obtained are presented in Figure 4. It was observed that a decrease in the binder content increases the thixotropy from 196.93 to 743.21 and decreases the pseudoplasticity from 0.8127 to 0.6679, respectively. This can be explained as follows. As the binder content is decreased, the viscosity increases and less binder is available for the system. It therefore requires a higher mixing time and higher rotations per minute (rpm) for achieving a homogeneous mixture.

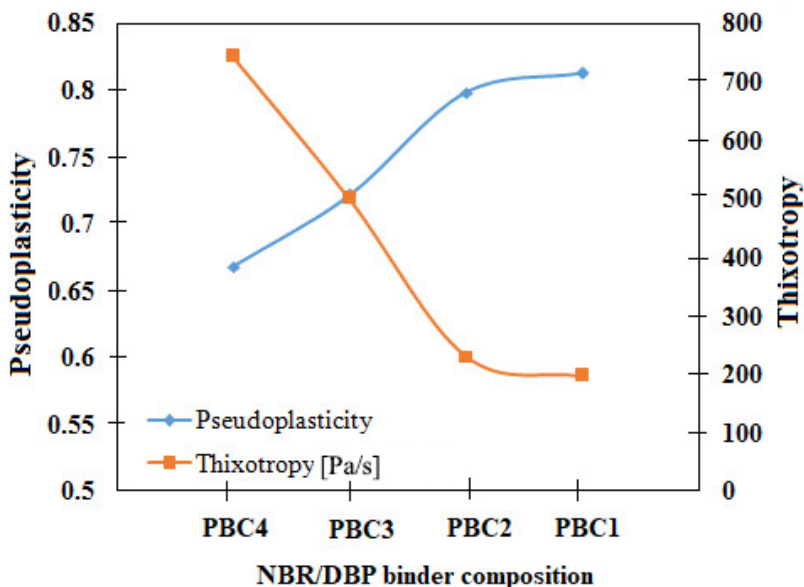
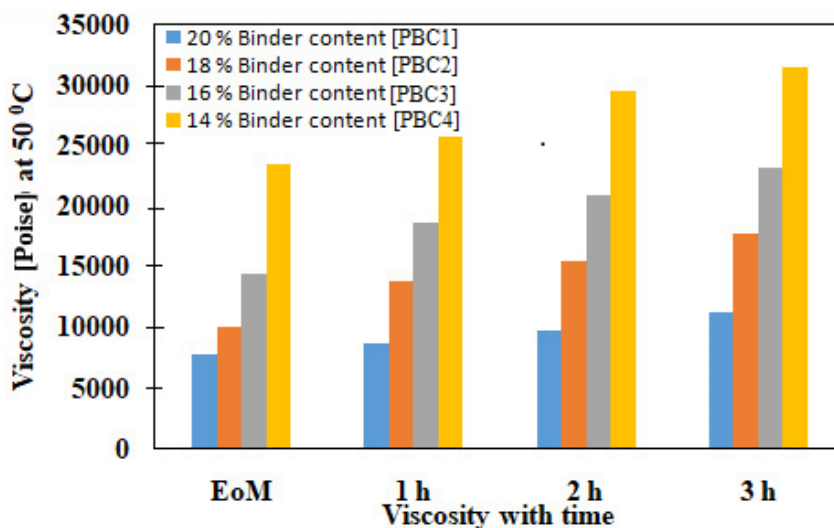


Figure 4. Effect of NBR/DBP binder content on pseudoplasticity and thixotropy

The different composite propellant compositions were processed to illustrate the end of mix (EoM) viscosity and viscosity build-up on varying the binder content from 20 to 14% using a viscometer (Brookfield) and the results obtained are listed in Table 3. The data shown in Table 3 evidently specify that as the binder content is decreased from 20 to 14%, the EoM viscosity of the propellant slurry increases from 7680 to 23360 Poise at 50 °C. Furthermore, from 20 to 16% binder content, the EoM and viscosity build-up shows sequential increases in viscosity, but beyond 16% binder content an abrupt change in EoM and viscosity build-up is observed. As the binder component (liquid part) is decreased in the composition its viscosity increases. The EoM viscosity and viscosity build-up are shown in Figure 5. The viscosity of the HTPB propellant was 6700 Poise, which is low compared to the NBR/DBP propellant. The higher viscosity of the NBR/DBP propellant is attributed to the higher viscosity of the NBR/DBP binder (220 Poise) compared to the HTPB binder (40 Poise) [8, 20].

Table 3. EoM viscosity and viscosity buildup data at 50 °C

Period at 50 °C	Viscosity [Poise]			
	PBC1	PBC2	PBC3	PBC4
EoM	7680	9920	14400	23360
After 1 h	8640	13760	18560	25600
After 2 h	9600	15360	20800	29440
After 3 h	11200	17600	23040	31360

**Figure 5.** Effect of NBR/DBP binder content on the EoM viscosity and viscosity build-up (data from Table 3)

5.3 Pot life

Pot life is the time from mixing the ingredients together to the point at which the mixed slurry is no longer useable for casting in a mould. A pot life study was carried out for these propellant compositions. Initially there is no sudden increase in viscosity, which is more or less constant, which indicates a high pot life as shown in Figure 6. The developed composition has a pot life of more than 12 h, whereas the composite propellant formulation processed with HTPB binder has a limited pot life of 6-8 h [21, 22]. Thus the prepared composite propellant has a better pot life than the HTPB based composition, which is very desirable for the processing of flawless large sized rocket motors. Pot life is determined by a plot of viscosity vs time, as shown in Figure 6.

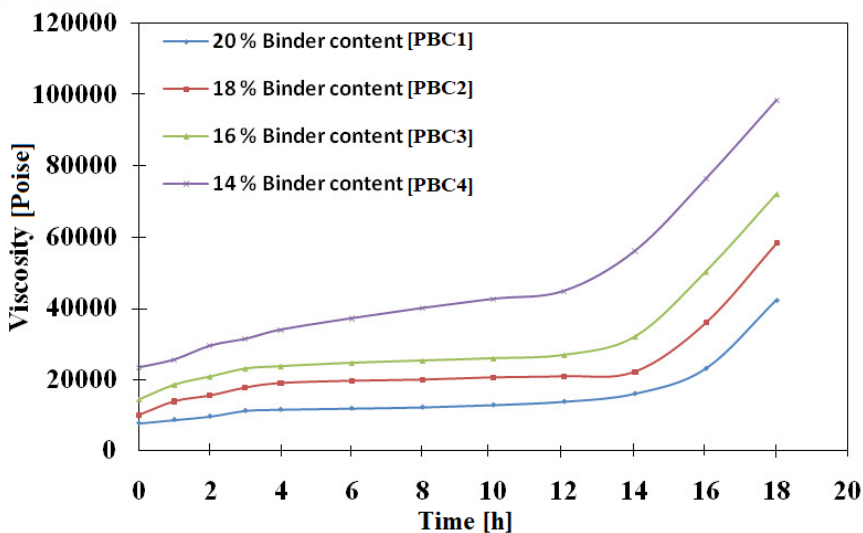


Figure 6. Viscosity build-up with time

5.4 Spreadability

The spreadability coefficient (SC) is determined by the change in shape of the sample under its own weight at 50 °C after 30 min.

$$SC = (d_1 - d_2)/d_2 \quad (1)$$

where d_1 is the diameter of the propellant after 30 min (in mm) and d_2 is the initial diameter (in mm). The SC and yield stress of the studied formulations are listed in Table 4. It is clear from these data that a decrease in the spreadability coefficient and an increase in yield stress is due to a decrease in the binder to solid ratio in compositions PBC1 to PBC4. As the binder content is decreased from composition PBC1 to PBC4, the yield stress increases and consequently a reduced flow of the slurry, resulting into lower spreadability of propellant slurry, is observed. A higher value of spreadability is desirable for obtaining good flawless propellant grains.

Table 4. Spreadability coefficient and yield stress of the different compositions

Parameter	PBC1	PBC2	PBC3	PBC4
<i>SC</i>	1	1	0.98	0.40
Yield stress (± 3) [Pa]	57.61	68.25	81.34	220

The propellant formulation with 14% binder content showed very low spreadability (40%), which is an indication of a very high yield stress and a high EoM viscosity. The HTPB based propellants also showed nearly same value of yield stress at 86% solid loading [17].

5.5 Hardness, density and mechanical properties

Hardness, density and mechanical properties were determined on cured propellant samples at 27 °C. After curing the samples were visually analyzed and data on the effect of binder content on the mechanical properties, such as TS, E-mod and % E of the cured propellant, are presented in Table 5.

Table 5. Hardness, density and mechanical properties of NBR/DBP binder based compositions

Composition	Hardness [Shore A]	Density [kg/m ³]	TS [kgf/cm ²] ([MPa])	E-mod [kgf/cm ²] ([MPa])	% E [%]
PBC1	55	1748	6.03 (0.591)	18.00 (1.765)	65.00
PBC2	60	1776	6.10 (0.598)	24.00 (2.354)	54.00
PBC3	65	1802	6.60 (0.647)	35.15 (3.447)	43.64
PBC4	70	1836	9.88 (0.969)	75.00 (7.355)	24.00

The hardness of the propellant formulations was found to be in the range of 55 to 70, an appreciable change in hardness. Incremental increases in hardness were observed by virtue of the increasing rigidity imparted to the composition by the decrease in binder to solid ratio. The density of the studied formulations was in the range of 1748 to 1836 kg/m³. The sequential increase in density for compositions PBC1 to PBC4 is due to replacement of the binder (which is of lower density, 1025.7 kg/m³) with solid AP (which is of higher density, 1950 kg/m³). Due to the higher density of the NBR/DBP binder (1025.7 kg/m³) compared to the HTPB binder (920 kg/m³), NBR/DBP based propellants have a greater density, 1836 kg/m³, than HTPB based propellants, 1777 kg/m³ [18].

The data in Table 5 reveal that % E decreases, while TS and E-mod increase with a decrease in binder content from 20 to 14% in the compositions. The solid filler particles impart reinforcement to the propellant, which enhances

the mechanical strength of composite propellant grains, consequently TS and E-mod increase and % E decreases with decreasing binder content. The TS (6.2 kgf/cm², 0.61 MPa) and E-mod (34.3 kgf/cm², 3.36 MPa) of HTPB based propellants are lower than those of NBR/DBP based propellants. However % E of an HTPB based propellant (45%) is higher than that of a NBR/DBP based propellant [8].

5.6 Ballistic properties

The acoustic emission technique in the presence of an inert atmosphere was used to determine the burning rates at 58.83 (5.883), 68.64 (6.864) and 78.45 bar (7.845 MPa) at 27 °C. The propellant grains were made from the solid strand burning rate (SSBR) samples (6×6×150 mm) [18]. The burning rate dependency on pressure (P) follows the exponential relation (Equation 2a). However this relation was converted into a linear relationship after taking logs (Equation 2b). This linear relationship was used for the calculation of the pressure index (n) from the slope of the curve.

$$r = a \cdot P^n \quad (2a)$$

$$\ln r = \ln a + n \ln P \quad (2b)$$

The data obtained are presented in Table 6 and Figure 7. The calorimetric value (Cal-Val) of the studied propellant formulations are also listed in Table 6.

Table 6. Ballistic properties of NBR/DBP binder based compositions

Composition	Cal-Val [cal/g] ([J/g])	Burning rate [mm/s] at pressure [bar] ([MPa])			n
		58.83 (5.883)	68.64 (6.864)	78.45 (7.845)	
PBC1	1215 (5079)	4.02	4.10	4.21	0.159
PBC2	1389 (5806)	4.73	4.92	5.06	0.234
PBC3	1475 (6166)	5.25	5.45	5.7	0.284
PBC4	1582 (6613)	6.2	6.54	6.9	0.371

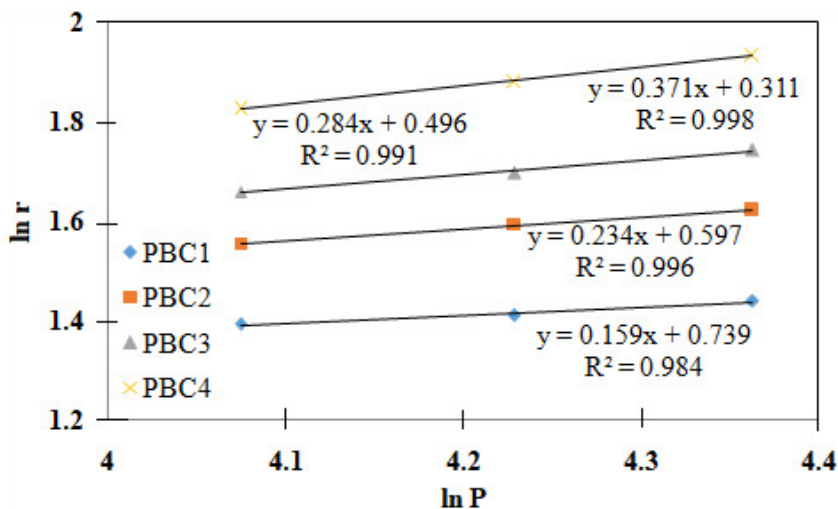


Figure 7. Determination of n values

The SSBR at 68.64 bar (6.864 MPa) with binder contents from 20 to 14% in the compositions was in the range of 4.10 to 6.54 mm/s. The data also reveal that the burning rate increases by around 60% with a decrease in binder content in PBC1 to PBC4 compositions. Enhancement in the burning rate of compositions from PBC1 to PBC4 is probably due to improved oxygen balance and the concomitant flame temperature. An HTPB/DOA based propellant shows a burning rate of 6.11 mm/s at 68.64 bar (6.864 MPa) for 86% solid loading, which is lower than that of an NBR/DBP binder propellant composition [8]. It may be seen from Table 6 that there was an almost 105% increase in n , from 0.159 to 0.371, with the decrease in binder content in PBC1 to PBC4 compositions. This is probably due to the higher pressure index of AP. The value of n for HTPB based propellant was 0.41, which is marginally higher than for the NBR/DBP based composition [8].

It is observed from the data in Table 6 that the Cal-Val increased in the range of 1215 to 1582 cal/g (5079 to 6613 J/g) for PBC1 to PBC4 compositions. In propellant formulations with an increase in the active ingredient AP, the Cal-Val increases. The Cal-Val of the NBR/DBP based propellants was found to be higher than that of the HTPB based propellants [8].

5.7 Thermal properties

The thermal properties of the studied compositions PBC1 to PBC4 were studied using the DSC-TGA technique and the thermograms obtained are presented in Figures 8 and 9. The DSC thermograms showed an endotherm around 250 °C due to the phase change of AP from orthorhombic to cubic, followed by a small decomposition peak around 300 °C and a final decomposition peak around 391 °C, for all of these compositions. AP in propellant compositions showed two peaks for low temperature and high temperature decomposition exotherms. In the low temperature region, only 30% decomposition occurred as the reaction is initiated at the surface and did not penetrate into the interior since it is limited by an intermosaic block of AP crystals, and above this temperature it decomposes completely [23, 24]. The thermal decomposition of pure AP exhibited an endotherm at 240 °C due to phase transition and decomposition exotherms at about 300 and 400 °C, which will be referred to as the low temperature decomposition and high temperature decomposition exotherm. The decomposition of AP depends on its degree of purity.

As the binder content was decreased, the final decomposition peak shifted from 391 to 387 °C. These findings revealed that decreasing the binder content from 20 to 14%, caused a shift in the final decomposition peak in these composite propellant formulations to a slightly lower temperature due to sequential enhancement of the content of the energetic ingredient AP [5, 24, 25]. The formulation with binder content 14% (PBC4) exhibited thermal decomposition at 387 °C, which is low compared to the other compositions (PBC1, PBC2 and PBC3), and consequently exhibited the highest enhancement in the burning rate. The HTPB/DOA based propellant composition for 86% solid loading exhibited a sharp exothermic decomposition peak at around 394 °C, which is marginally higher than for the NBR/DBP based propellant. Probably the higher decomposition temperature is the reason for a lower burning rate of HTPB/DOA based propellant than PBC4 [8, 25].

The TGA study indicated that the compositions from 20 to 14% binder content exhibited a weight loss in three stages in the temperature ranges of 180 to 200 °C, 290 to 330 °C and 330 to 400 °C, of approximately 11-16%, 19-26% and 47-49%, respectively. The mass loss pattern represented the initial weight loss at ~190 °C due to evaporation of volatile materials such as plasticizer DBP, the low temperature decomposition of AP at ~310 °C and the high temperature decomposition of AP at ~390 °C, respectively. These results revealed that a decrease in binder content from 20 to 14% caused final weight loss shifts in the composite propellant formulations to a slightly lower temperature due to minor sequential enhancement of the energetic ingredient AP.

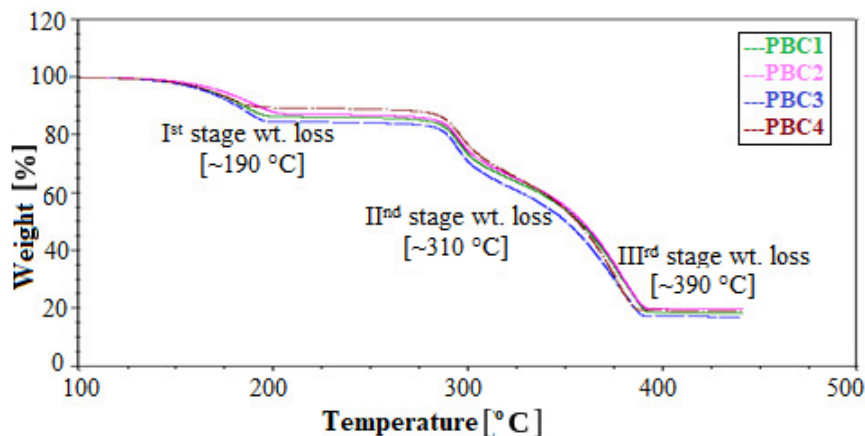


Figure 8. TGA curves demonstrating the influence of the binder content

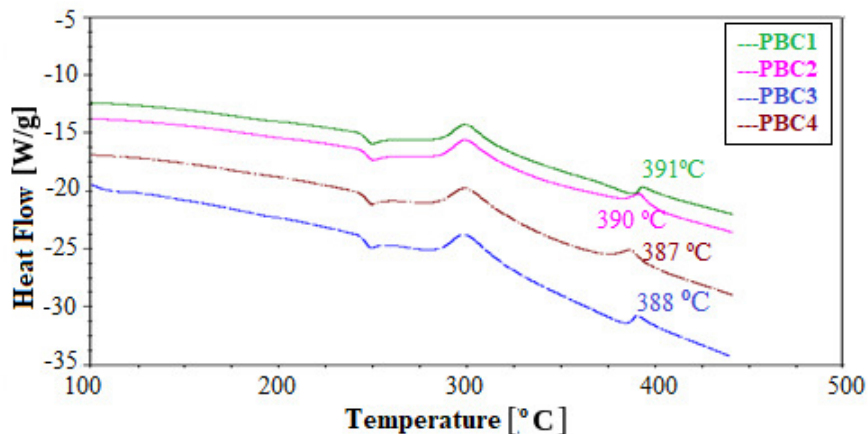


Figure 9. DSC curves demonstrating the influence of the binder content

6 Conclusions

The present study focused on the development of high performance composite propellant formulations using a nitrile butadiene rubber (NBR) based binder system. The following conclusion can be drawn from this study:

- ◆ NBR/DBP based propellants are better than HTPB based ones in terms of higher density specific impulse (theoretical), longer pot life, higher density, higher tensile strength and modulus, higher Cal-Val and lower

pressure exponent. HTPB based propellants are better than NBR/DBP based propellant compositions due to their higher specific impulse (theoretical), lower viscosity and higher % elongation.

- ◆ NBR/DBP based propellants give comparable spreading coefficients and higher burning rates compared to HTPB based propellants. NBR/DBP based propellants give good rheological, mechanical and ballistic properties. The developed compositions have a pot life greater than 12 h, which is very desirable for casting large sized rocket motors.
- ◆ NBR/DBP propellants can be tailored for needs based applications in future missile applications. The effect of different plasticizers, in addition to process aids, will be further studied in order to explore the vast potential of this binder and curing system.

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