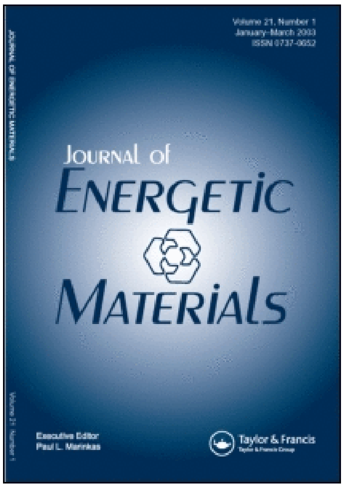

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Studies on Different Types of Nitrocellulose in Triple Base Gun Propellant Formulations

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Currently triple base propellants are used for tank gun ammunition. Nitroguanidine (NQ) propellant is the most promising among them due to various advantages like low flame temperature, flashlessness, low barrel erosion, long shelf life, etc. Therefore, it will continue to be used in the field of gun propulsion systems for several years to come. However, there is scope for enhancing the performance of triple base propellant with respect to energy level and mechanical properties.

Nitrocellulose (NC) is the energetic binder cum fuel used in the triple base composition propellant and constitutes a sizeable percentage of the compound. Hence, one of the promising triple base compositions was selected, and a systematic study was carried out by using different types of NC (having varying percentages of nitrogen content) to study the variation in mechanical properties, energy content, linear burning rate coefficient, and pressure exponent. The results are discussed in this paper.

Keywords: Nitrocellulose, triple base propellant, force constant, mechanical properties

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Introduction

Triple base gun propellants play an important role in high-performance guns and field artillery because the triple base gun propellants have certain advantages like low flame temperature (and hence less barrel wear), flashlessness, nonhygroscopicity, low toxicity of combustion products, lower cost to manufacture, ability to burn more completely, less residue, less sensitivity to friction and impact compared to double base propellants, and high shelf life [1–4]. The triple base propellant itself contains nitroguanidine/picrite, nitroglycerine (NG), and nitrocellulose (NC) as the major ingredients. Nearly 55% of the triple base propellant consists of nitroguanidine, which contributes to the flashlessness and cool nature of the propellant. NG acts as the energetic plasticizer and contributes to the energy level. It is responsible for effective gelatinization, while NC plays an important role in giving a high force constant and increasing the mechanical property of the propellant [5–6].

The current British and Indian triple base propellants for high-caliber guns contain NC (Type B) with nitrogen content 13.1%, whereas the American triple base propellants contain NC (Pyro) with nitrogen content 12.6%. However, to the best of our knowledge no work has yet been reported on the comparative advantages and disadvantages of various types of NC in the triple base gun propellant formulation. Some studies have been carried out in India for improving the mechanical properties and energy level by incorporating fine RDX and the energetic plasticizer DANPE (1,5-diazido-3-nitraza pentane) for partial replacement of nitroguanidine [7, 8]. On these lines, energy improvement studies have also been reported in China by incorporating 1,5-ditriazo-3-nitroazapentane [9].

In the present study four types of triple base formulations were made using three types of NC, viz., NC (Type A) with 12.2% nitrogen, NC (Pyro) with 12.6% nitrogen, and NC (Type B) with 13.1% nitrogen. Various theoretical as well as ballistic studies have been carried out.

Experimental

Three triple base propellant compositions 1, 2, and 3 along with standard composition (NQ) were formulated (Table 1). The triple base propellant composition contained 28% NC along with 22.5% NG, 48% picrite, and 1.5% carbamite. Composition 1 contains NC (Type A) with 12.2% nitrogen, Composition 2 contains NC (Pyro)

Table 1
Chemical formulations: Percentage of ingredients

	Composition			
Ingredients	1	2	3	4 (NQ)
Nitrocellulose	(Type A, 12.2% N) 28	(Pyro 12.6% N) 28	(Type B 13.1% N) 28	(Type B 13.1% N) 20.8
Nitroglycerine	22.5	22.5	22.5	20.6
Picrite	48	48	48	55
Carbamite	1.5	1.5	1.5	3.6

with 12.6% nitrogen, and Composition 3 contains NC (Type B) with 13.1% nitrogen. The standard NQ Composition 4 contains 20.8% NC, 20.6% NG, 55% picrite, 3.6% carbamite, with NC (Type B) having 13.1% nitrogen. Even though Compositions 1 and 2 utilize a soluble type of NC, the degree of nitration is different, and hence the performance is expected to vary. The processing of these compositions was carried out using the solvent acetone : Alcohol (70:30). It was observed that Composition 3 required a higher percentage (27%) of solvent as compared to Compositions 1 and 2 (19%). The theoretical thermochemical values of the composition are given in Table 2.

The mechanical properties testing—compression strength (CS) and percentage compression (% C)—was carried out on a number of extruded cylindrical grains of length-to-diameter ratio 1:1 using a Hounsfield H25KS material testing machine and are displayed in Table 3. The average of five readings was computed. For dynamic evaluation the gun propellants Compositions 2 and 4 showing promising results were extruded in a heptatubular geometry using a hydraulic press. The ballistic aspects of the propellants were determined by closed vessel (CV) firing tests. The CV capacity was 700 cc, and the loading density 0.2 g/cc. From the CV firing tests, the ballistic parameters as force constant (F), pressure exponent (α), and linear burning rate coefficient (β_1) were calculated as per internal ballistic solutions [10] and are given in Table 4. The dynamic evaluation of Compositions 2 and 4 was carried out with 120 mm FSAPDS proof shot weighing 6.85 kg using the 120 mm tank gun, where pressure was measured by a copper crusher gauge and muzzle velocity by Doppler radar. The results are given in Table 5.

Table 2
Theoretical thermochemical values

Parameters	Propellant composition and type of NC			
	1 Type A	2 Pyro	3 Type B	4 NQ
Force constant, J/g	1064	1077	1088	1028
Flame temperature, K	2973	3010	3070	2800
Cal-val, cal/g	951	964	987	873
Gamma value	1.2431	1.2424	1.2410	1.2513
Specific energy, kJ/kg	4377	4427	4515	4091

Table 3
Mechanical properties

Properties	Propellant composition			
	1	2	3	4 (NQ)
Compression strength, kg/cm^2	395	316	293	270
Percentage compression	35	31	39	8

Results and Discussion

The theoretical thermochemical calculations (Table 2) indicate the improvement in energy level (1064–1088 J/g) with the three types of NC used in Compositions 1, 2 and 3 as compared to the existing Composition 4 (1028 J/g), which is in service. The mechanical property results (Table 3) exhibited significant improvement in compression strength (395 kg/cm^2) and percentage compression (35%) for Composition 1 followed by 316 kg/cm^2 (CS), 31 (%C) for Composition 2, and 293 kg/cm^2 (CS), 39 (%C) for Composition 3 over the existing Composition 4 [270 kg/cm^2 (CS) and 8 (%C)]. As seen from the data given in Table 4, the force constant determined experimentally is in close agreement with the theoretically predicted values given in Table 2. The reduction in gamma values (Table 2) from 1.2431 (Composition 1) to 1.2424 (Composition 2) and further to 1.2410 (Composition 3) has helped to improve the specific energy of propel-

Table 4
Closed vessel evaluation results (0.2 g/cc loading density)

	Propellant composition			
Parameters	1	2	3	4 (NQ)
Force constant, J/g	1062	1071	1082	1021
Linear burning rate coefficient, β_1	0.129	0.131	0.140	0.145
Pressure exponent, α	0.63	0.64	0.65	0.72

Table 5
Dynamic trial results

Propellant composition	Charge mass (kg)	Chamber pressure (MPa)	Muzzle velocity (m/s)
2	8.0	499	1648
4	8.59	471	1648

lant, thereby enhancing the ballistic performance of triple base gun propellant as compared to the NQ composition, where the gamma value is 1.2513. The flame temperature of these three compositions that is marginally higher—2973 K (Composition 1), 3010 K (Composition 2), 3070 K (Composition 3)—than 2800 K (Composition 4) but is still within the desirable limits for gun propellants. The graphical representation of force constant and flame temperature for all four compositions is given in Figure 1.

The ballistic results of the propellant evaluation (Table 4) indicate that the propellant with NC (Type A) (12.2% N) (Composition 1) gave the least linear burning rate coefficient β_1 (0.129 cm/s/MPa) followed by 0.131 cm/s/MPa for Composition 2 with NC (Pyro) (12.6% N) and 0.140 cm/s/MPa for Composition 3 with NC (Type B) (13.1% N). These three β_1 values ranging from 0.129 to 0.140 cm/s/MPa are lower than that of Composition 4 (0.145 cm/s/MPa). It is encouraging to note that the pressure index values were in the range of 0.63–0.65 for Composition 1, 2, and 3 as compared to 0.72 for Composition 4. The graphical representation of linear burning rate

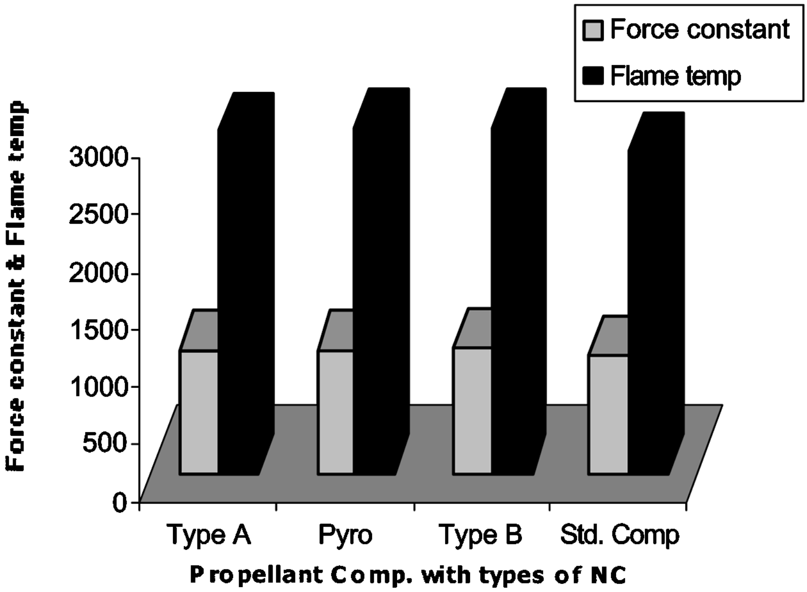

Figure 1. Force constant and flame temperature of propellant compositions.

coefficient β_1 and pressure exponent α of all four compositions is given in Figure 2.

The graphical representation of compression strength and percentage compression of all four compositions is given in Figure 3. Superior mechanical properties of Composition 2 can be attributed to its NC (Type A) with 12.2% N having ether alcohol solubility (EAS) more than 95%, resulting in better gelatinization of NC. NC (Pyro) with 12.6% N has a solubility of 89% in ether alcohol, whereas the Composition 4 comprising NC (Type B) with 13.2% N has a solubility of 8–12% in ether alcohol. The effect of nitrogen content on the solubility of NC in ether alcohol has also been discussed by Miles [11], who concluded that mechanical properties depend on the nature of NC employed—that is, its molecular chain length and nitrogen content.

Composition 2 was selected for dynamic trials, as it had excellent mechanical properties and acceptable flame temperature, required a low percentage of solvent for processing (19%) than Composition 3 (27%), and had a higher force constant (1077 J/g) than Composition

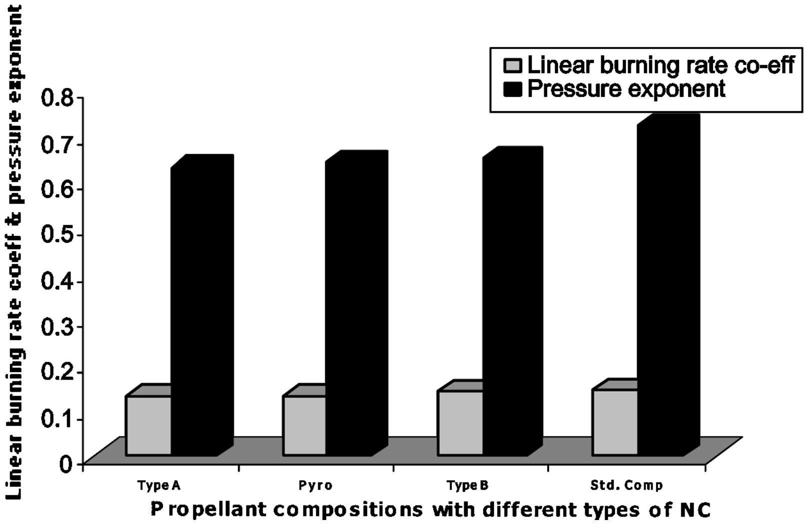

Figure 2. Linear burning rate coefficient and pressure exponent of propellant compositions.

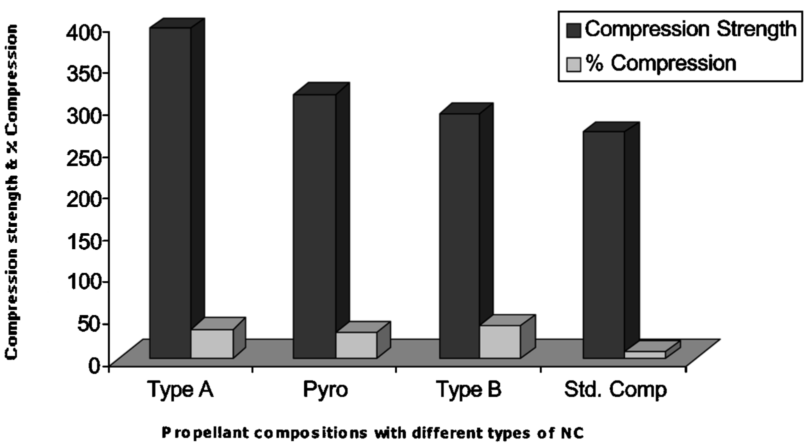

Figure 3. Compression strength and percentage compression of propellant compositions.

1 (1064 J/g). The dynamic trial results (Table 5) indicate that Composition 2 gave a muzzle velocity (mv) of 1648 m/s (at a chamber pressure of 499 MPa), which was at par with Composition 4 with a higher charge mass of 8.59 kg.

Conclusion

It can be concluded that (1) improvement in energy level is possible by varying the type of NC. Composition 3 in particular gives the highest force constant due to a higher percentage of nitrogen available in NC (Type B). (2) Superior mechanical properties have been shown in Composition 1 due to the lower percentage of nitrogen available in NC (Type A), which has contributed to ether alcohol solubility of more than 95%, resulting in better gelatinization in the acetone-alcohol solvent. (3) Dynamic evaluation of the promising Composition 2 shows that muzzle velocity matching to that of Composition 4 can be achieved with a lower charge mass at a marginally higher chamber pressure.

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