Defence Science Journal, Vol 46, No 2, April 1996, pp 83-86

Studies on the Effects of RDX Particle Size on the Burning Rate of Gun Propellants

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ABSTRACT

The ballistic properties of RDX-based propellants are highly dependent on the particle size of RDX used. The effect of RDX particle size on the burning rate and pressure exponent of the gun propellant was studied. Propellant formulation containing RDX to the extent of 60 per cent in the composition was processed with varying particle size of RDX. Finished propellants in heptatubular and cord geometry were evaluated for ballistic aspects by closed vessel firing in a 700 cc vessel at a loading density of 0.18 g/cc. The data obtained clearly indicate that increase in particle size of RDX increases the burning rate as well as the pressure exponent.

1. INTRODUCTION

Cyclic nitramine (cyclotrimethylene trinitramine), commonly known as RDX, is a potential high energy ingredient in the propellant used for high performance guns. It is well-known that unlike linear nitramines, such as nitroguanidine (picrite), RDX exhibits the property of melt layer phenomena during propellant combustion. Accordingly, the ballistic properties of the propellant are highly dependent on the particle size of RDX used in it. The aim of the present work was to study the effect of variation of RDX particle size on the burning rate and pressure exponent (α) of the propellant. Linear burning rate coefficient (β_1) and the pressure exponent (α) are two important parameters to be considered while formulating a propellant for gun application. Chemical compositions and process conditions being maintained the same, the effects of variation in RDX particle size on the burning characteristics of the propellant were studied.

2. EXPERIMENTAL WORK

A nitrocellulose-RDX-based composition with 60 per cent RDX was formulated. The composition with 60 per cent RDX was selected for the studies based on theoretical computation of a nitramine-based propellant formulation to meet the energy level required for a particular ammunition. The four different batches of propellant were processed by incorporating a particular particle size of RDX in each batch. The four different particle sizes selected for the studies were close to 3, 5, 10 and 20 micron. Propellant dough was made by acetone-alcohol solvent mixture in a sigma blade incorporator. Propellant strands were extruded in cord and heptatubular configuration using proper die/pin assemblies in a vertical hydraulic press. Propellant strands were cut to required length and dried to the desired V.M. limit and then subjected to various tests. The processing conditions for all the batches were identical. Chemical formulation of the composition studied, along with the exact particle sizes of RDX used, is given in Table 1. The physical characteristics of the propellant as realised are noted in Table 2.

To study the burning rate behaviour, all the propellant batches were subjected to closed vessel (CV) firing tests. The vessel capacity was 700 cc and the loading density in all the cases was 0.18 g/cc. All samples were conditioned at 27 °C for 24 h before firing. From the *dp/dt vs* pressure curve, obtained in

Received 22 February 1995, revised 03 July 1995

CV firing tests, the ballistic parameters such as linear burning rate coefficient (β_1) and pressure exponent (α) were computed as per internal ballistic solutions[1,2].

Table 1. Chemical formulation and actual RDX particle size used

Constituent		Contents, %		
Nitrocellulose (N % 13.1)		30.00		
RDX		60.00		
Dioctylphthalate (DOP)		4.00		
Dinitrotoluene (DNT)		5.0		
Carbamite		1.0		
Experiment	I	II	III	IV
RDX Particle Size micron (Determined by Fisher subsieve sizer)	3	4.6	10	21

Table 2. Physical characteristics of the four propellant batches

Experiment			II		III		IV	
Geometry Ballistic	CORD	M/T	CORD	M/T	CORD	M/T	CORD	M/T
size(mm)	2.54	1.34	2.62	1.37	2.63	1.39	1.72	1.43
Density (g/cm^3)	1.64	1.64	1.64	1.64	1.60	1.60	1.57	1.57

M/T, multitubular (heptatubular)

Table 3. Closed vessel firing results

Propellant geometry	Ballistic parameters	Average particle size of RDX (micron)			
		3.0	4.6	10	21.0
Heptatubular	Burning rate (r) at 140 MPa (cm/s)				31.5
	Linear burning rate coefficient (β_1) (cm/s/MPa)	0.095	0.11	0.15	0.21
	Pressure exponent (α)	0.74	0.80	0.96	1.04
Cord	Burning rate (r) at 140 MPa (cm/s)	16.6	19.8	27.3	36.9
	Linear burning rate coefficient (β_1) (cm/s/MPa)	0.12	0.14	0.19	0.24
	Pressure exponent (α)	11	1.19	1.23	1.33

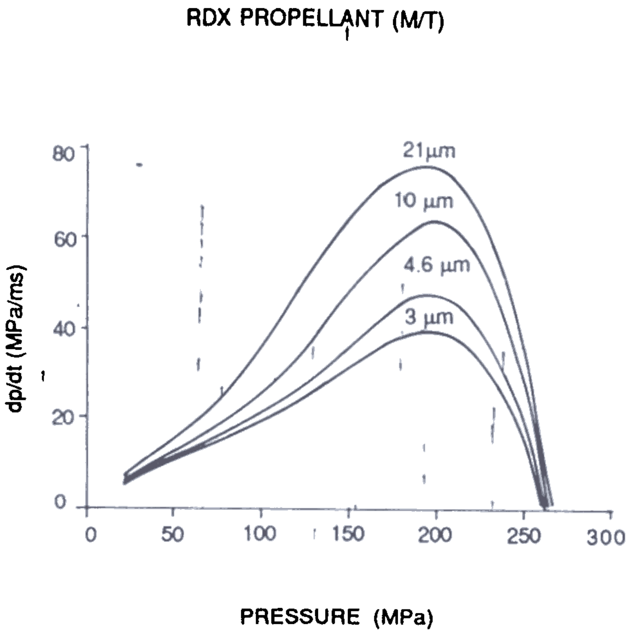

Figure 1 Pressure *vs dp/dt* curves for RDX propellant in multitubular (M/T) form.

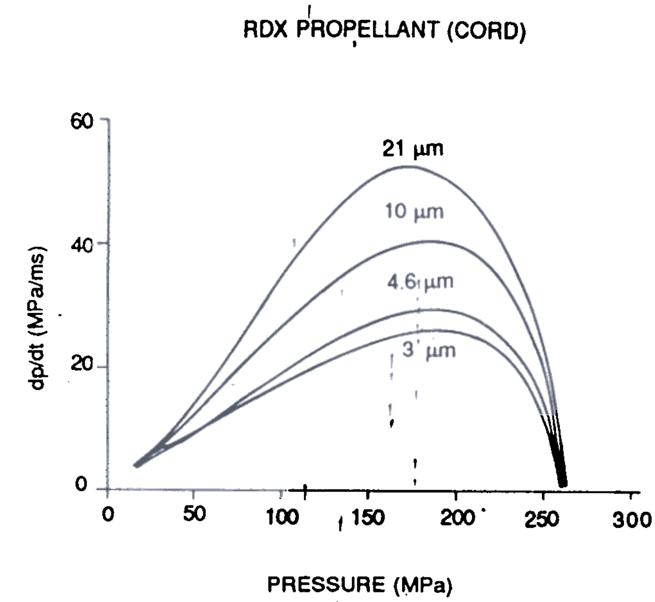

Figure 2. Pressure *vs dp/dt* curves for RDX propellant in cord form.

3. RESULTS & DISCUSSION

Curves of *dp/dt vs* pressure for the propellants in heptatubular and cord geometry are given in Figs 1 and 2, respectively. Graphs for log p *vs* log r for heptatubular and cord geometry are given in Figs 3 and 4 respectively. The ballistic properties determined by CV firing evaluation are given in

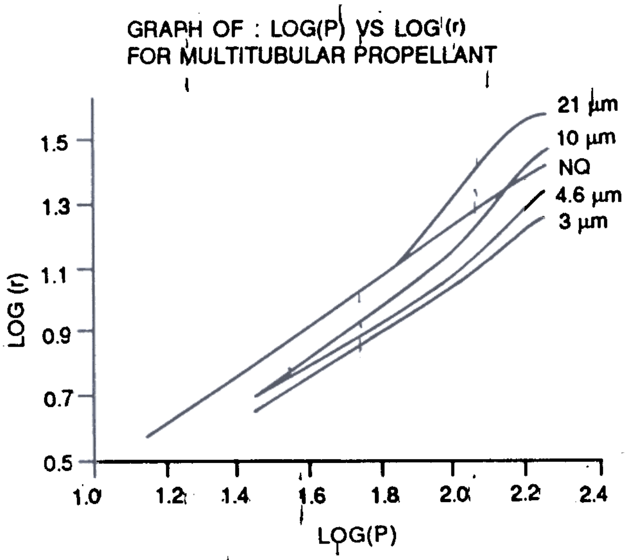

Figure 3. Log *p* vs log *r* graphs for RDX propellant in multitubular (M/T) form.

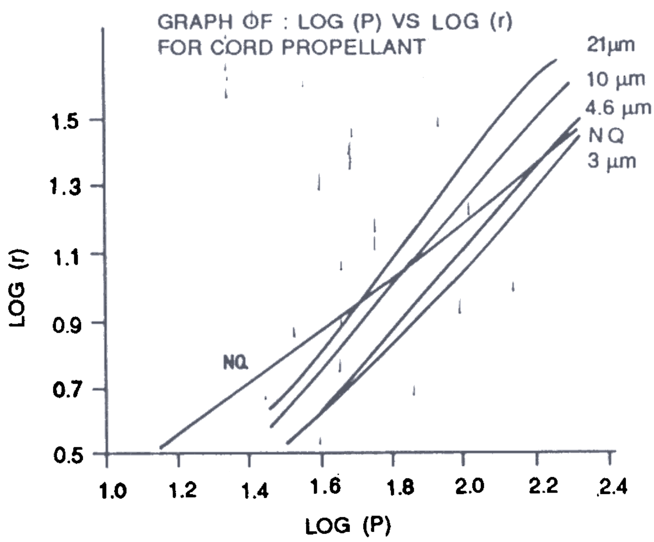

Figure 4. Log *p* vs log *r* graphs for RDX propellant in cord form.

Table 3. The maximum pressure up to which the present study was conducted was about 260 MPa. The data available from the CV test clearly indicate the considerable dependence of propellant burning rate on RDX particle size[3]; β_1 increased from 0.095 cm/s/MPa for 3 micron RDX to 0.24 cm/s/MPa for 21 micron, and the α value rose from 0.74 to 1.3 under the same conditions. However, the values of β_1, α and r for cord and heptatubular geometry were found to vary, the cord-shaped propellant giving higher values in all the cases. This difference appears to be due to approximation in the form function for multitubular shape and also ignition and burning characteristics of holes of the multitubular propellant. Separate study is proposed to be carried out to investigate this phenomenon.

Various mechanisms have been postulated for the burning behaviour of RDX by different authors. The melt layer phenomenon is widely agreed upon. Finer particles result in thicker melt layer while coarser particles give thinner melt layer, thereby resulting in slow and high burning rates. This mechanism of RDX-based propellant combustion is reported by Cohen and Strand[4]. Taylor[5] attributed the apparent high burn rates to convective combustion. According to him at high pressures when the melt layer is no longer continuous hot gases may flash into the porous solid and cause convective burning. Different authors have reported the dependence of RDX particle size on burn rate exponent and burning rate coefficient[6-11]. Use of higher particle size reduces the solid density of the propellant which is reflected in the density variation of the propellant. Inferior solid density in the case of higher particle size RDX may cause more chances of porous nature of the solid thereby increasing the chances of convective burning. As compared to the smooth surface the porous surface exposes more area for burning; accordingly, Pioberts law of burning may not be strictly applicable for deciding the ballistics. Also, at high pressures the coarser particles may eject out of the burning molten surface[12]. These particles will start burning separately whereby more chances of convective heat tranfer to the sub-layer will also result. The burning rate of a propellant is dependent on chemical composition and physical nature of ingredients. According to Vielles' theory $r = \beta_1 p^{\alpha}$ or $r = \beta_1 p$ when α is 1. The burning rate constants β_1 and α are dependent on the chemical composition of the propellant. β_1 is predominantly dependent on initial temperature of the propellant whereas α does not depend on initial temperature. Therefore, increase in burning rate (r), for a particular composition, due to particle size variation increases the α value.

Even though separate study was not conducted to evaluate the burning behaviour of HMX-based propellant, according to information available from the literature, burning behaviour of HMX is more or less similar to that of RDX. For both RDX and HMX, higher particle size increases the exponent and burn rate[13]. Linear nitramines like nitroguanidine follow the conventional burning behaviour, i.e lower the particle size, higher is the burning rate[14].

4. CONCLUSION

Burning characteristics of RDX-based propellants are dependent on the particle size of RDX and therefore for high energy propellant formulation for gun application the particle size control is very important.

ACKNOWLEDGEMENTS

We thank Dr Haridwar Singh, Director, High Energy Materials Research Laboratory, Pune, for his valuable guidance and encouragement.

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