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Ballistic Evaluation of LOVA Propellant in High Calibre Gun

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ABSTRACT

This paper presents the data obtained on dynamic firing of a cellulose acetate binder-based low vulnerability ammunition (LOVA) propellant using 120 mm fin-stabilised armour piercing discarding sabot (FSAPDS) kinetic energy ammunition. An optimised propellant composition formulated using fine RDX as an energetic ingredient and a mixture of cellulose acetate and nitrocellulose as binder was qualified fit for firing in a high calibre gun by its successful static evaluation for absolute ballistics using high pressure closed vessel technique. Dynamic firing of the propellant processed in heptatubular geometry was undertaken to assess the propellant charge mass. This propellant achieved higher muzzle velocity as compared to the standard NQ/M119 triple-base propellant while meeting the non-vulnerability characteristics convincingly.

Keywords: LOVA propellants, ballistic evaluation, FSAPDS ammunition, binder-based LOVA propellant

1. INTRODUCTION

The development of low vulnerability ammunition (LOVA) gun propellant has gained importance from the fact that accidental initiation of onboard ammunition happened to be the cause of major catastrophy, resulting in casualty of tank crew and loss of costly equipment[1]. Ammunition vulnerability is mainly due to the sensitivity of conventional nitricesters-based propellants[2]. The concept of LOVA gun propellant is evolved by formulating a propellant which is least sensitive to impact, friction and heat stimuli and meeting the ballistic requirements satisfactorily at par with the conventional propellants. Cellulose derivatives, such as cellulose acetate (CA), cellulose acetate butyrate (CAB), cellulose acetate propionate (CAP), ethyl cellulose (EC) are reported as promising inert binders in LOVA propellant formulations[3]. To compensate the energy loss caused by the replacement of nitroglycerine (NG) and partially of nitrocellulose (NC) by CA, the high energy nitramines like RDX in fine particulate form[4] is used as the energetic ingredient. This paper highlights the thermochemical data of a promising LOVA formulation and its ballistic properties by static evaluation using high pressure closed vessel (HPCV) technique and actual dynamic firing results.

2. EXPERIMENTAL PROCEDURE

2.1 Formulation & Processing

Exhaustive evaluation studies were carried out on cellulosic binder-based LOVA propellant[5]. In the present study, the authors have selected a

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propellant formulation containing 10 parts CA, 11 parts NC of 12.2 per cent nitrogen content, 5.5 parts triacetin, 71 parts fine RDX, 2 parts dinitrotoluene, 0.5 parts ethyl centralite and 1 part over 100 parts of basic composition, KNO_3. The processing of the propellant formulation was carried out by solvent method to get the finished propellant in heptatubular geometry with 2.3 length/diameter and 10 external diameter/internal diameter ratio.

2.1.1 *Vulnerability Study*

Vulnerability aspects of LOVA propellant were evaluated by carrying out the test for determining impact and friction sensitivity, ignition temperature, hot fragments conductive ignition temperature[2,6], etc.

2.1.2 *Ignition Study*

Varney[7,8], *et al.* reported that the ignition energy requirement of LOVA propellant is twice as that of conventional single-base propellant. Accordingly, the necessity for evaluating the ignitability of the LOVA propellant under development was felt before going for the dynamic firings. Different igniter materials, such as gun powder, boron/KNO_3, magnesium, teflon, viton and magnesium-based igniters were tried. Based on the analysis of ignition delay, conventional gun powder was selected as the promising igniter material.

3. BALLISTIC EVALUATION

3.1 Static Evaluation

Static evaluation by HPCV technique was carried out and HPCV (700 ml) was used for this purpose. Propellant was subjected to static firing at various loading densities from 0.2 g/ml to 0.32 g/ml. Since the propellant was planned to be dynamically tested in the gun up to 500 MPa, HPCV firing was carried out by gradually raising the loading density till the pressure realised in HPCV closely matched with the expected pressure in the gun. Absolute ballistic values were then calculated from the HPCV output using the internal ballistic solution[9]. *dp*/*dt* versus *P*, log *r* versus log *P* and the pressure versus time profiles as obtained from HPCV at the maximum loading density of 0.32 g/ml are given in Figs 1(a), 1(b) and 1(c).

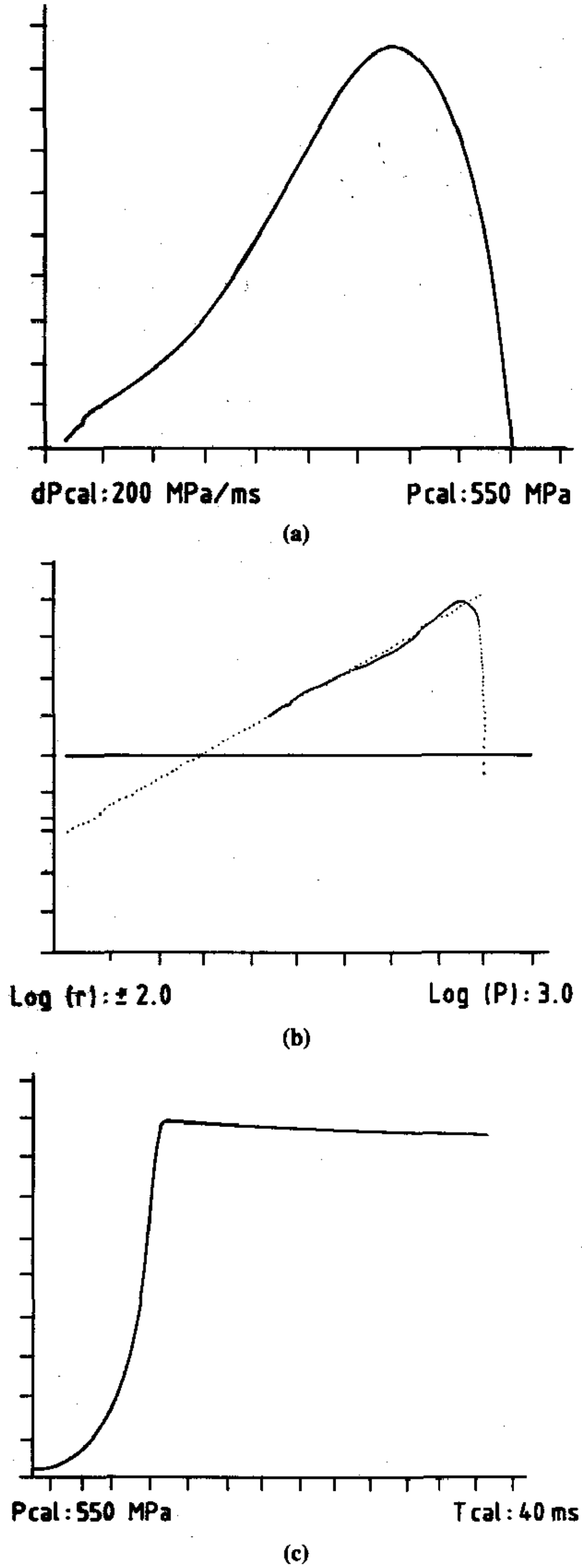

Figure 1. Static HPCV firing of LOVA propellant conditioned at 27°C at 0.32 g/ml loading density, (a) *dp/dt* versus *P*, (b) log *r* versus log *P*, and (c) pressure versus time profiles.

Table 1. Charge assessment dynamic gun firing of LOVA propellant

Propellant charge mass (kg)	Chamber pressure P_{max} (MPa)			Muzzle velocity (m/s)	
	Predicted	Achieved			
		Crusher gauge	Piezo gauge	Predicted	Achieved
6.5	220	197	201	1179	1180
7.0	247	232	223	1262	1263
7.5	276	279	NR	1344	1353
8.0	347	368	340	1426	1499
8.1	370	396	405	1531	NR
8.2	372	400	398	1533	1572
8.3	419	437	445	1548	1578
8.4	449	457	467	1564	NR
8.5*	463	470	482	1643	1645
8.6*	486	485	495	1666	1661

* Average of the five rounds fired NR - Not recorded

3.2 Dynamic Evaluation

Ward[10], *et al.* have reported the dynamic firing of different types of LOVA propellant in 105 mm tank gun. The propellant mass used was 4.98 kg. Ulrike Jeck-Prosch[11] reported the gun firing of LOVA propellant in 40 mm and 120 mm simulator and based on their findings they have concluded that LOVA propellant must be proved in original ammunition.

A 120 mm gun barrel with its kinetic energy ammunition belonging to fin-stabilised armour piercing discarding sabot (FSAPDS) category was selected for the dynamic evaluation of the LOVA propellant under development. The ballistic prediction of this propellant in 120 mm FSAPDS ammunition was carried out using the absolute ballistic parameters of this propellant achieved by HPCV evaluation. The chamber pressure measurement carried out using copper crusher gauge and piezoelectric gauge during the dynamic firing, using the FSAPDS projectile of 6.85 kg with 7.5 kg–8.6 kg propellant charge mass are given in Table 1. Control firings were also carried out using conventional triple-base propellant to comparatively evaluate the performance of the LOVA propellant. Pressure-time profile obtained by piezoelectric gauge for LOVA propellant and conventional triple-base propellant are given in Figs 2 and 3.

Table 2. Propellant formulations, their theoretical thermochemical values and ballistic data from CV–firing

Chemical formulation	
Cellulose acetate (CA)	10.0 parts
Nitrocellulose (NC) (Nitrogen content 12.2 %)	11.0 parts
Triacetin (TA)	5.5 parts
Dinitrotoluene (DNT)	2.0 parts
RDX	71.0
Carbamite	0.5
KNO_3	1 part over 100 parts
Thermochemical values	
Flame temperature (K)	2853
Force constant (J/g)	1081
Cal. val (cal/g)	815
Ballistic data from closed vessel firing (loading density 0.2 g/ml)	
Force constant (J/g)	1070
P_{max}, (MPa)	263.5
β_1(cm/s/MPa)	0.082
Pressure exponent (α)	0.8153

4. RESULTS & DISCUSSION

Thermochemical data for the selected formulation and the ballistic data obtained from closed vessel evaluation at 0.2 g/ml loading density are given in Table 2. The studies carried on the selected formulation under evaluation and the detailed vulnerability test results are given in Table 3. Linear burn rate coefficient (β_1) for gun propellants is generally considered as a constant for the composition. HPCV evaluation of LOVA propellant under development indicated that the value of β_1 changes according to the loading density and this change is quite significant in predicting the

Table 3. Vulnerability properties

Impact sensitivity Ht. of 50% explosion (cm)	58
Friction sensitivity (insensitive up to) (kg)	36
Ignition temperature (°C)	> 220

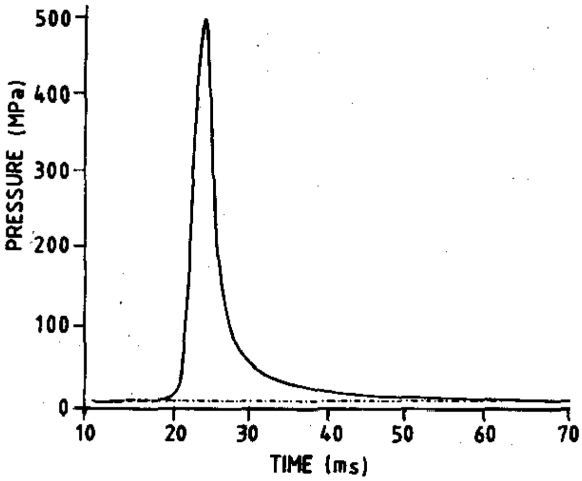

Figure 2. Pressure versus time profiles obtained by piezoelectric gauge during dynamic gun firings for LOVA propellant.

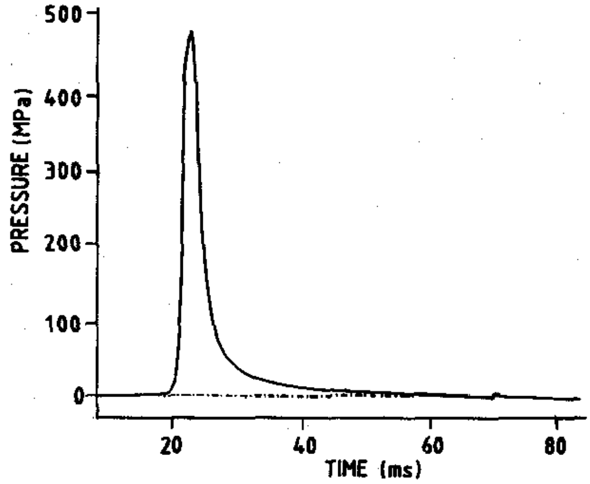

Figure 3. Pressure versus time profiles obtained by piezoelectric gauge during dynamic gun firings for triple-base propellant NQ/M 119.

gun pressure. For reliable and correct prediction of the chamber pressure during dynamic firing, the β_l value from HPCV of matching pressure levels have to be applied in the computation. As seen from the closed vessel profiles, the burning of LOVA propellant is quite normal, almost at par with the conventional propellants. Pressure-time profile obtained during the dynamic firings indicated that the combustion behaviour of this propellant is more or less similar to the conventional propellants.

From the results of HPCV carried out for both LOVA propellant (Table 4) and the conventional triple-base propellant (Table 5), it is seen that β_l for both the propellants shows increasing trend as the loading density increases. However, this change (increasing loading density) is more in the case of LOVA propellant. β_l value at 0.25 g/ml loading density for LOVA propellant recorded was 0.0965 cm/s/MPa and at 0.32 g/ml loading density, the same was 0.108 cm/s/MPa, whereas the β_l value of 0.14 cm/s/MPa for triple-base NQ/M propellant had increased to only 0.147 cm/s/MPa, this difference in change of β_l value according to loading density is considered to be due to the higher pressure sensitivity of LOVA propellant. Similarly, the pressure exponent value for conventional propellant remained almost constant while for LOVA propellant, it has shown a linear increase in the pressure exponent (α) value. It is also observed that the achieved force constant is considerably more than the theoretical force constant. The change in force constant at higher loading densities may be due to the inaccuracy of the cooling correction applied for computing the force constant. Results of dynamic firing as given

Table 4. High pressure closed vessel results of LOVA propellant

Parameters	Propellant results				
	(1)	(2)	(3)	(4)	(5)
Loading density (g/ml)	0.2500	0.2750	0.3000	0.3100	0.3200
P_{max} (MPa)	350.2300	399.1600	448.1300	470.4600	491.7600
dp/dt (MPa/ms)	90.0900	119.6900	153.1900	170.5100	188.1000
Force constant (J/g)	1085.5000	1097.7000	1102.7600	1109.8000	1113.0000
α	0.8635	0.8775	0.8899	0.9120	0.9172
β_l (cm/s/MPa)	0.0965	0.1010	0.1042	0.1057	0.1080

Table 5. High pressure closed vessel results of conventional NQ/M propellant

Parameters	Propellant results				
	(1)	(2)	(3)	(4)	(5)
Loading density (g/cc)	0.250	0.275	0.300	0.310	0.320
P_{max} (MPa)	329.800	380.300	423.700	444.160	464.500
dp/dt (MPa/ms)	82.310	106.910	131.120	140.110	153.990
Force constant (J/g)	1032.000	1057.000	1054.000	1053.000	1064.000
α	0.738	0.710	0.721	0.700	0.712
β_1 (cm/s/MPa)	0.141	0.142	0.144	0.146	0.147

Composition NQ has NC (N_2 % 13.1), 20.8; NG, 20.6; Picrite, 55.00; Carbamite, 3.6; Potassium cryolite, 0.3 (parts).

in Table 1 indicate that the chamber pressure realised by crusher gauge and piezoelectric gauge are in close agreement. Moreover, the predicted chamber pressure calculated using the β_1 value at the appropriate pressure level from HPCV have closely matched with the realised pressure during dynamic firing. Pressure-time profile of LOVA propellant and conventional propellant shown in Figs 2 and 3 indicate the smooth burning characteristic on the expected lines. The muzzle velocity realised for the LOVA propellant at the adjusted charge mass (8.6 kg) on matching pressure level (490 MPa) has been superior in comparison to conventional propellant adjusted charge mass (8.46 kg). This is due to the improved energy output of LOVA propellant.

5. CONCLUSION

LOVA gun propellant based on RDX as the energetic ingredient is found to be slightly higher pressure sensitive as compared to conventional propellant. However, this will not seriously affect the smooth performance of the propellant in the gun. LOVA propellant with RDX as energetic ingredient can satisfactory meet the ballistic requirement of high performance kinetic energy ammunition.

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