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Impact, Friction, Shock Sensitivities and DDT Behaviour of Advanced CMDB Propellants

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ABSTRACT

This paper reports results of impact, friction and shock sensitivities of CMDB propellants containing AP, RDX, PETN and their combinations. Results of impact and friction sensitivities indicate that CMDB propellants containing AP are highly sensitive and AP-based compositions are more impact and friction sensitive than RDX and PETN-based compositions, and that these sensitivities are proportional to oxygen balance of the composition, which is in agreement with earlier findings. Inclusion of high explosives like RDX and PETN increases the shock sensitivity of CMDB formulations, whereas AP-based compositions are least shock sensitive. There exists a relationship between shock sensitivity and VOD of the individual oxidiser/high energy ingredient incorporated in the formulation. Shock amplitude values of 87 and 46 k bar in CMDB and DBP, as determined by NOL card gap test, suggest that CMDB propellants are much more shock sensitive than DBP. Composite propellants are insensitive to shock, as they did not undergo detonation even at zero card gap. Results of DDT behaviour of CMDB propellants show that they are more prone to deflagration to detonation transition under adverse conditions.

1. INTRODUCTION

Composite Modified Double Base (CMDB) propellants offer most energetic propulsion system for space vehicles and strategic missiles[1,2]. CMDB propellants take the advantages of both Composite (CP) and Double Base Propellants (DBP). Thus, oxidisers like Ammonium Perchlorate (AP) are incorporated in NC-NG matrix in

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CMDB system. In order to achieve further higher performance, metallic fuels like aluminium (*Al*) and high energy materials like RDX, HMX, PETN, etc. are also incorporated[3]. Inclusion of high energy materials/oxidisers alongwith liquid nitrate ester in CMDB compositions makes the system extremely hazardous and sensitive. During various stages of processing, handling and transportation, solid propellants are subjected to mechanical stimuli such as impact, friction and shock[4]. Further, high energy propellants tend to undergo Deflagration-to-Detonation Transition (DDT) due to the presence of large amounts of high explosive components in the system[5,6]. While impact and friction sensitivities depend upon the oxygen balance of the composition[7], shock sensitivity depends upon the texture and the ability of detonation of the composition[8]. Generally, DDT is less common in well manufactured rocket propellants. However, it depends to a large extent on confinement, permeability which is a function of sample porosity, particle size distribution and particle shape, sample diameter (critical diameter), bed length and compaction due to ignition pressurisation[5]. A few studies have been carried out in the past on the impact and friction sensitivities of CMDB ingredients and their physical mixtures and low content RDX and PETN (1 to 10 parts) based systems[9,10]. However, information available on high oxidiser/high energy additive-based advanced CMDB propellants on sensitivity aspect is scanty and hence a systematic study was undertaken to evaluate friction, impact and shock sensitivities of these propellants with 30 per cent oxidiser content. DDT aspect was studied by non-destructive experiments using high pressure combustion vessel.

2. EXPERIMENTAL

Spheroidal Nitrocellulose (SNC) prepared in ERDL pilot plant[11], Nitroglycerine (NG), RDX and PETN of required purity obtained from Ordnance Factories; AP of 99 per cent purity procured from M/s Wimco, Bombay, and *Al* of 99 per cent purity received from M/s Metal Powder Company, Madurai, were used. CMDB propellant compositions were made by slurry casting technique[4]. Compositional details are given in Table 1.

Julius Peters apparatus was used to determine impact sensitivity with fall weight of 2 kg. The friction sensitivity was determined with the help of Julius Peters apparatus

Table 1. Details of propellant compositions

Composition No.	Spheroidal nitro-cellulose (SNC)	Desensitised nitro-glycerine (80 NG:20 desensitiser)	Oxidiser/Energetic materials			Metallic fuel *Al*
			AP	RDX	PETN	
1	30	40	30			
2	30	40		30		
3	30	40			30	
4	30	40	15			
5	30	40	15		15	
6	30	40			15	
7	30	35	21			14

(model SG 41 D 132) having range[12] of 0.5 – 36 kg. For shock sensitivity cylindrical charges of different diameters were subjected to shock from 25 g of PETN-based plastic explosive[13,14]. CMDB compositions were evaluated for NOL gap test. Booster used was pressed tetryl (ρ 1.51 g/cc) of 5.08 cm length. Moderately confined propellant charges of 36.6 mm diameter and 139.7 mm length were used for evaluation. Cellulose acetate sheets were used as shock attenuators. The criterion of detonation was punching of hole in the witness plate. The measure of charge sensitivity is the gap length at which there is 50 per cent probability of detonation[15].

DDT behaviour of CMDB propellant was investigated by determining the maximum pressure generated at various loading densities of the propellant in a closed vessel. A rocket motor of 950 mm length, 114 mm inner diameter with closed ends was used. Suitable strain gauges were used for recording the response. Time required from initiation of ignition to achievement of maximum pressure was also recorded.

3. RESULTS AND DISCUSSIONS

3.1 Impact and Friction Sensitivities

Results of impact sensitivity are given in Table 2 in terms of height for 50 per cent explosion and fall energy. From these results AP-based compositions appear to be most sensitive to impact with a height of 50 per cent explosion of 26 cm and RDX-based CMDB compositions appear to be least sensitive with a height of 50 per cent explosion of 47 cm. PETN-based compositions gave intermediate value of 32 cm. These results suggest that inclusion of AP in RDX and PETN containing CMDB propellants makes the system sensitive, compositions containing both RDX-PETN in the same formulation were found to be least sensitive with a height of 50 per cent explosion of 36 cm, which is intermediate between that of RDX and PETN-based compositions.

Results of friction sensitivity are also included in Table 2. Trend observed for friction sensitivity was similar to that for impact sensitivity. The order of friction

Table 2. Results of impact and friction sensitivities of various CMDB compositions

Composition No.	Impact sensitivity		Friction sensitivity		Oxygen balance
	Height for 50% explosion (cm)	Fall energy (kg m)	Not exploded (wt, kg)	Exploded (wt, kg)	
	26	0.52	2.8	3.2	– 15.65
2	47	0.94	24.0	25.2	– 32.33
3	32	0.64	6.4	7.2	– 28.88
4	25	0.50	4.0	4.2	– 23.99
5	27	0.54	4.2	4.8	– 22.27
6	36	0.72	12.0	12.8	– 30.61
7	23	0.46	4.2	4.8	– 31.28

sensitivity was AP > PETN > RDX-based compositions (figure of insensitivity of 2.8, 6.4, 24 kg respectively). RDX-PETN-based compositions were less sensitive than AP-RDX and AP-PETN-based compositions (figure of insensitivity of 12.8, 4, 4.2 kg respectively).

A plot of log of 50 per cent height of explosion for CMDB compositions and log of figure of insensitivity against log of oxygen balance of compositions are given in Figs. 1 and 2 respectively. Results obtained indicate that impact and friction sensitivities are directly proportional to oxygen balance of compositions (Table 2). Thus AP, AP-RDX and AP-PETN-based compositions with higher oxygen balance of –15.65 to –23.99 are more sensitive than RDX, PETN and RDX-PETN-based compositions with relatively lower oxygen balance (–28.88 to –32.33). Higher sensitivity of AP-*Al*-based compositions may be due to highly exothermic reactions of oxidisers and fuel on impact. Thus, linear relationship between sensitivity and oxygen balance holds good for all combinations, except AP-*Al*-based formulations.

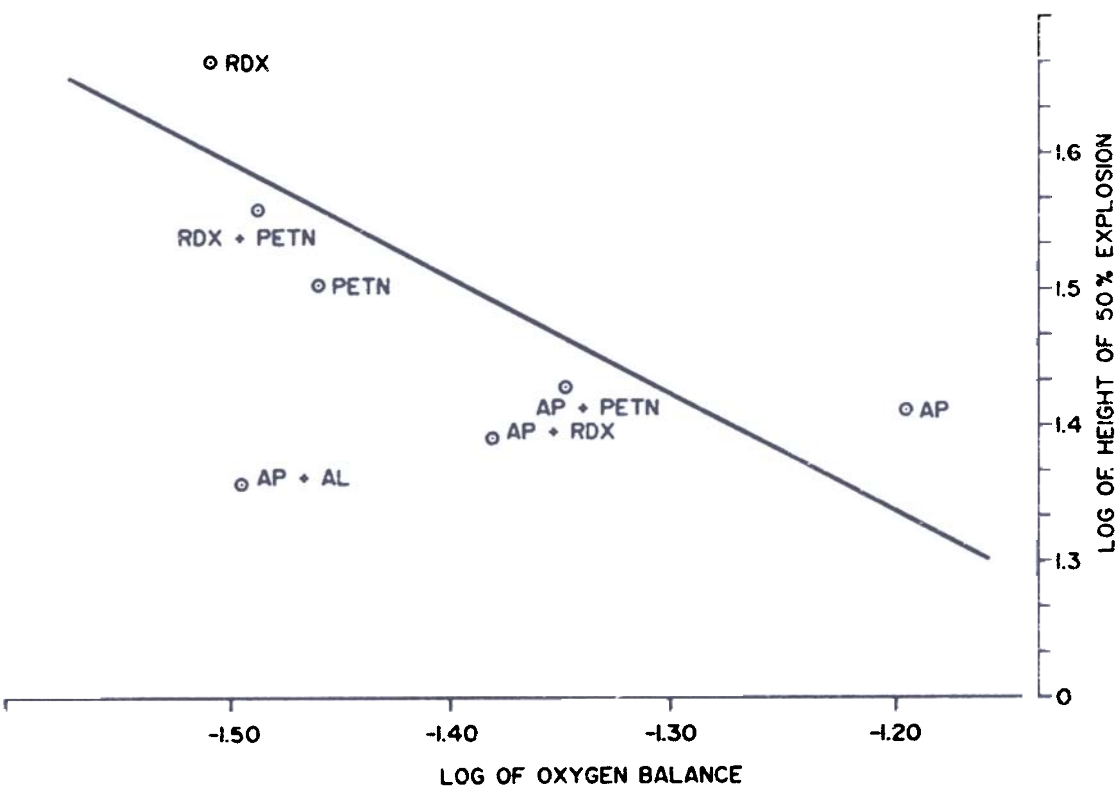

Figure 1. Relationship between impact sensitivity and oxygen balance.

Initiation of decomposition, explosion and detonation by the agency of impact, friction and shock is attributed to formation of hot spots. These hot spots are generated in explosive mass by a number of possible routes including viscous heating, frictional heating and adiabatic compression of entrapped gases[17]. A number of physical and chemical properties, in addition to reaction kinetics, may influence the birth of hot spots. These may include heat evolved in the decomposition, heat capacity, thermal conductivity, latent heats of fusion and evaporation of the explosives, crystal hardness, crystal shape, dissolved gases, surface tension and vapour pressure in liquid[16,17]

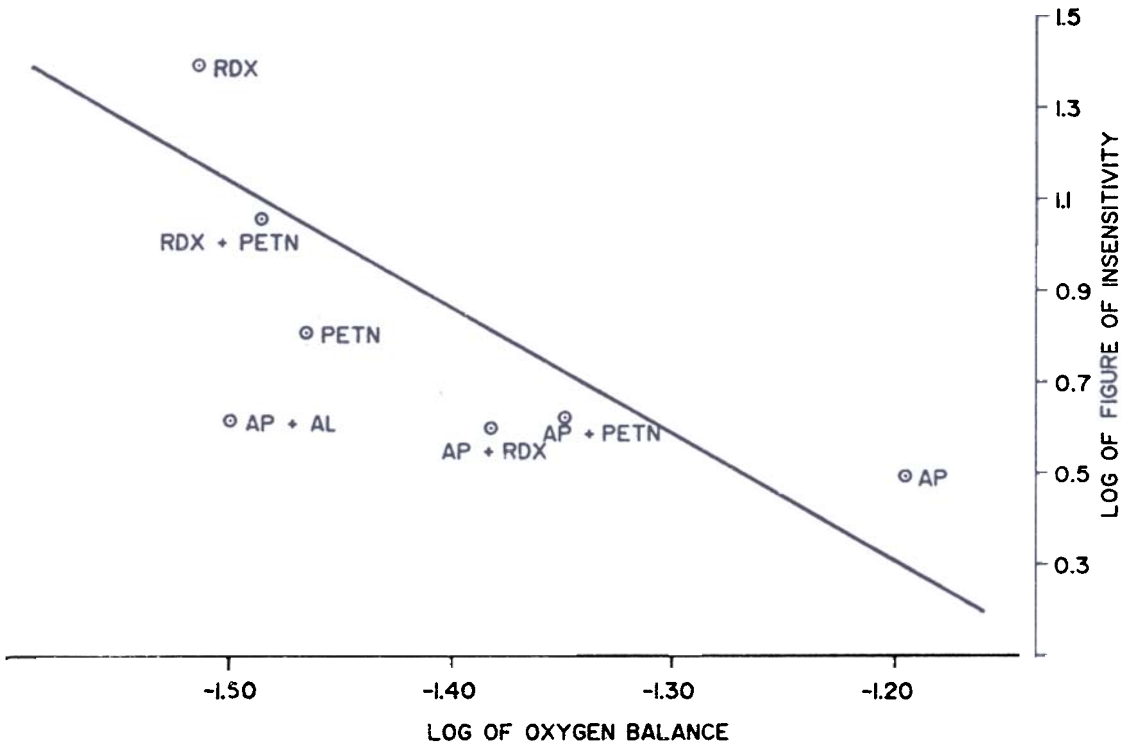

Figure 2. Relationship between friction sensitivity and oxygen balance.

3.2 Shock Sensitivity

Results of shock sensitivity of CMDB compositions are given in Table 3. With critical diameter more than 45 mm but less than 54 mm, AP-based CMDB propellants were found to be least shock sensitive, whereas RDX and PETN-based compositions with critical diameter less than 9 mm are highly sensitive. Inclusion of AP along with RDX and PETN brought down the shock sensitivity, as evident from critical diameter more than 9 mm for these compositions. Formulation containing both RDX and PETN gave critical diameter less than 9 mm. AP-*Al*-based composition, although less sensitive than RDX and PETN-based compositions, was found to be more sensitive than AP-based composition, as reflected by critical diameter less than 45 mm, but more than 36 mm.

A comparison of the results of critical diameter for shock sensitivity with the detonation velocities of oxidiser/high energy ingredients of CMDB compositions shows that a correlation exists between critical diameter of propellant and VOD of oxidiser/high energy ingredients. Thus, low sensitivity of AP-based compositions may be attributed to its[18] low VOD (2,500 m/s), as compared to that of RDX and PETN (8,750 and 8,400 m/s respectively[8]).

The results of NOL card gap test for CMDB propellants are given in Table 4. For ease of comparison results of CP and DBP are also included. The results show that CP did not undergo detonation at zero card gap, whereas DBP underwent detonation with gap of 17 cards. CMDB propellant detonated at card gap of 85, suggesting thereby that CMDB propellants are more sensitive to shock. Shock amplitude values were determined by using formula $P=105\ e\ -0.0358\ x$, where P is

Table 3. Critical diameter of various CMDB compositions for shock sensitivity

Composition No.	Witness plate observation at critical diameter (mm)					
	9	18	27	36	45	54
	No dent	No dent	No dent	No dent	No dent	Dent
2	Dent	Dent	Dent	Dent with punched hole		
3	Dent	Dent	Dent	Dent with punched hole		
4	No dent	Dent				
5	No dent	Dent				
	Dent	Dent				
7	No dent	No dent	No dent	No dent	Dent	

shock amplitude value in k bar and x is thickness of cards[15] in mm. Shock amplitude value for 50 per cent probability of detonation for CMDB propellant was of the order of 87 k bar as compared to that of 46 k bar for DBP. These results indicate that CMDB propellants are much more shock sensitive than CP and DBP.

3.3 DDT Behaviour of CMDB Propellants

DDT is very important from mission point of view and becomes critical if propellant breaks into pieces due to stresses or more surface area is exposed due to inhibition failure. DDT results of CMDB propellants having loading densities from 0.005 to 0.02 g/cc in a closed cylindrical motor are given in Table 5. Pressure-time (P–t) output is given in Figs. 3 and 4. P_{max} obtained at lowest loading density of

Table 4. Results of card gap test

Propellant system	Number of cards	Go/No go	Cards' thickness (mm)	Shock amplitude (k bar)
DBP	0	Go		
(NC, NG-based)	15	Go		
	17	Go	4.9	88.1
	20	No go	5.6	85.9
Composite	0	No go		
(AP, *Al*, HTPB-based)				
CMDB		Gc		
(NC, NG, AP, *Al*-based)				
	75	Go		
	80	Go		
	83	Go	22.8	46.4
	85	No go	23.2	45.7

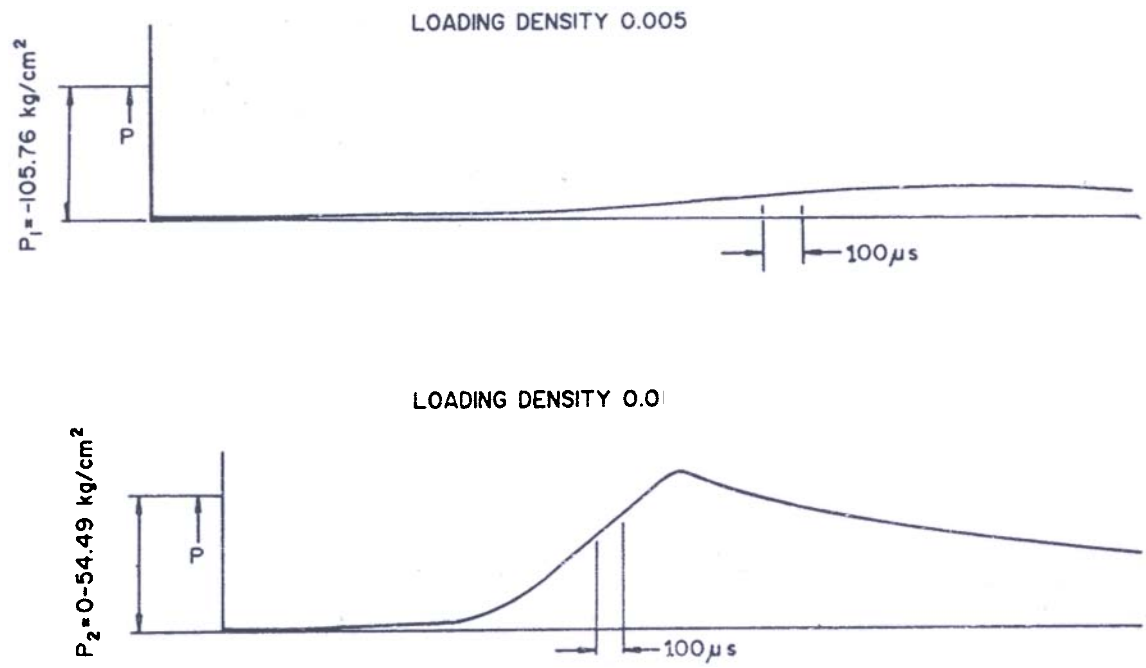

Figure 3. Pressure-time output obtained during DDT experiments at loading density 0.005 and 0.01.

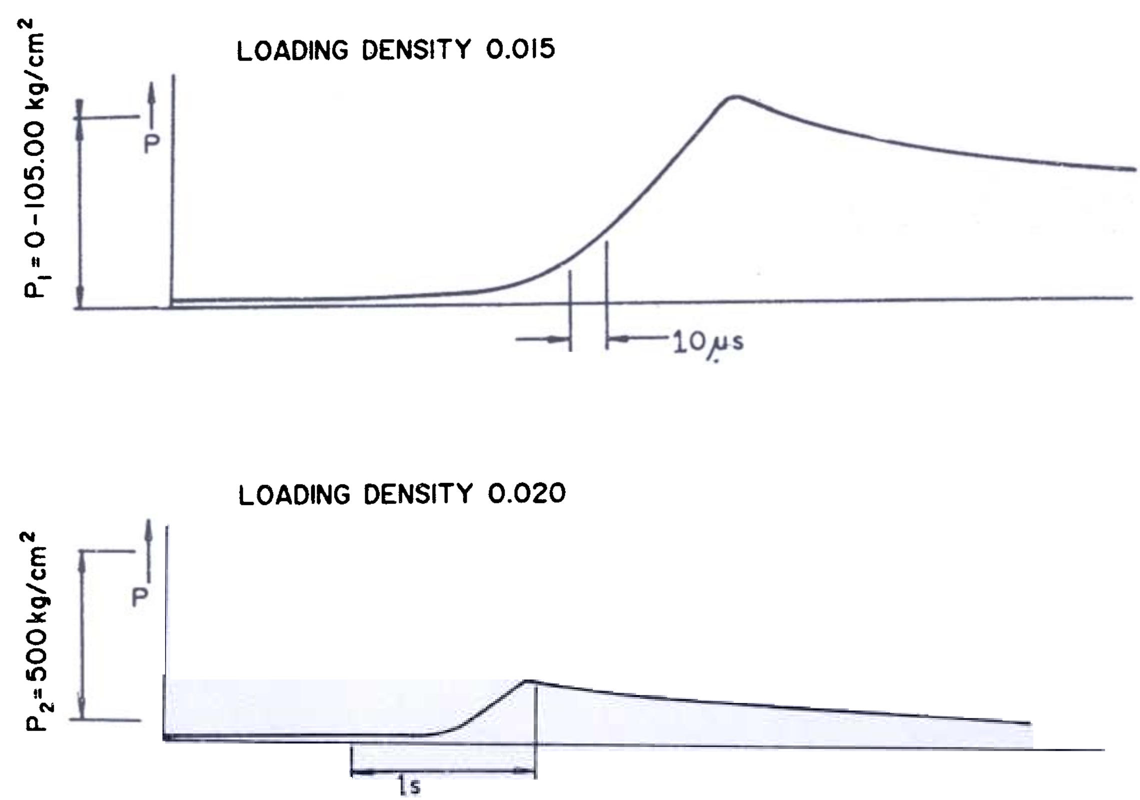

Figure 4. Pressure-time output obtained during DDT experiments at loading density 0.015 and 0.02.

0.005 g/cc was taken as a reference point. It was observed that increasing loading density to 0.01 and 0.015 g/cc gave P_{max} 40 to 50 per cent higher than expected and at 0.02 g/cc loading density P_{max} was increased by 100 per cent than theoretically predicted value. Consequently, time interval from ignition initiation to attainment of P_{max} decreased from 1418-1460 ms (Loading Density (LD) 0.005 to 0.01 g/cc) to 1047 ms (LD 0.015 g/cc) and finally to 529 ms (LD 0.02 g/cc). These results suggest that CMDB propellants have tendency to undergo DDT under adverse conditions.

Table 5. Results of DDT in terms of maximum pressure at various loading densities

Loading density (g/cc)	P_{max} expected (kg/cm^2)	P_{max} observed (kg/cm^2)	Difference (P_{max} observed $-P_{max}$ expected) (kg/cm^2)	% increase in observed P_{max}	Time from initiation to P_{max} (ms)
0.005	Reference	22.2			1418
0.010	44.46	62.4	17.9	40.4	1460
0.015	66.69	105.0	38.3	57.5	1047
0.020	88.92	179.3	90.4	101.7	529

4. CONCLUSION

AP-based CMDB propellants are more sensitive to impact and friction than RDX and PETN-based propellants. Inclusion of AP along with RDX/PETN makes the system more sensitive to impact and friction. On the otherside, RDX/PETN-based CMDB compositions are more sensitive to shock than AP-based CMDP propellants. Impact and friction sensitivities results of CMDB propellants are in agreement with oxygen balance of compositions. Shock sensitivity results show direct relationship with VOD of oxidiser/high energy ingredients (AP, RDX, PETN). Card gap test results indicate that CMDB propellants require 87 k bar pressure to undergo detonation. Further, CMDB systems have tendency to undergo DDT under adverse conditions.

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