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Influence of Various Process Parameters on Mechanical Properties and Ballistics of Nitramine-Based Advanced CMDB Propellants

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ABSTRACT

This paper reports the influence of important process parameters, namely mixing time and batch size; on the mechanical properties and ballistics of nitramine-based advanced CMDB propellants. Considerable improvement to the tune of 67 per cent in tensile strength was observed at a mixing time increase of 60-135 min. Scaling up of batch size from 8 to 25 kg resulted in 30 per cent higher tensile strength. Recorded enhancement of burning rate was of the order of 8 per cent in both the sets of experiments. Ballistically modified composition revealed 11-12 per cent increase in burning rate at all the pressure ranges, on combined increase in mixing time (55 to 85 min) and batch size (5-17 kg). These findings are in line with those reported for composite and ballistically modified double-base propellants.

1. INTRODUCTION

Composite modified double-base (CMDB) propellants offer advanced propulsion system for modern missiles and space mission applications[1]. This class of propellants comprises ammonium perchlorate (AP) dispersed in double-base (DB) matrix. Nitramines like RDX and HMX are also incorporated in the CMDB system in order to achieve superior performance[2]. CMDB propellants can be prepared either by advanced casting powder (ACP) technique or by slurry cast technique (SCT). SCT is preferred to ACP technique in view of cost-effectiveness and versatility. Steps involved in the manufacture of CMDB propellants by SCT are mainly ingredient processing,

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blending of ingredients in a mixer, casting of the slurry obtained in evacuated moulds and curing[3]. In the case of composite propellants (CP) prepared by SCT as well as ballistically modififed double-base propellants (DBP) frequent unacceptable variations in burn rates and mechanical properties are reported[4, 5]. These variations are attributed to various process parameters like the mixing time of the ingredients, batch size, mixing temperature, particle size of the ingredients and physical distribution of ballistic modifiers[4, 5]. In view of almost non-existent information on these aspects for CMDB propellants, a systematic study was undertaken to assess the effect of important parameters, namely ingredient mixing time and batch size on ballistics and mechanical properties of CMDB propellants of practical value based on AP and RDX combination. This information is of immense importance from the point of view of propellant development programme which involves scaling up of production from laboratory scale to plant scale.

2. EXPERIMENTS

Spheroidal nitrocellulose (SNC), nitroglycerine (NG) desensitised with diethyl phthalate (DEP), AP, RDX and *Al* were conditioned at 20 °C and mixed in vertical planetary mixers (supplied by M/s Drias and Janke and Kunkel). The slurry thus obtained was cast in moulds and curing was carried out at 60 ± 0.5 °C in suitable ovens. The selected propellant composition contained 39 per cent SNC, 30 per cent NG, 6 per cent AP, 14 per cent RDX, 3 per cent *Al*, 6.5 per cent non-explosive plasticiser and 1.5 per cent 2-NDPA. SNC comprised of 90 per cent NC (12.2 per cent N), 7.2 per cent NG and 2.8 per cent carbamite.

The calorific value (cal-val) of the propellant was determined using Julius Peters bomb calorimeter. The tensile strength (TS) and per cent elongation of propellant samples were determined by using Instron Universal Materials Testing Machine (Model 1185) at cross-head speed of 50 mm/min. The dimensions of test samples were 35 mm guage length, 6 mm width, and 3 mm thickness. The ballistic data was generated by subjecting the propellant grains of 190 mm length, 110 mm outer diameter and 76 mm inner diameter to static evaluation in mild steel rocket motors. Pressure-time profile was obtained using suitable strain guage in conjunction with Hewlett-Packard data acquisition system. The results obtained for burning rates and mechanical properties during this study have the accuracy of the order of ± 0.5 per cent.

3. RESULTS AND DISCUSSION

During the first phase of study only one process parameter (either mixing time or batch size) was varied at a time while other process parameters like mixing temperature, curing temperature were kept constant. Vertical mixers of 50 kg and 25 kg capacities were used for the first and second sets of experiments respectively. The results obtained are given in Table 1.

In order to ensure reliability of results, identical ingredients were used for all sets of experiments. The propellants prepared during a given set of experiments gave almost identical values for cal-val and density.

Table 1. Influence of variation in process parameters on characteristics of nitramine-based CMDB propellant

	Mixing time (a) (min)			Batch size (b) (kg)		
	60	110	135	8	17	25
Physical Properties						
Cal-Val (cal/g)	1122	1131	1130	1130	1122	1124
Density (g/cc)	1.60	.61	1.61	1.60	1.61	1.60
Mechanical Properties						
Tensile strength (kg/cm^2)	9.5	13.0	14.5	10.0	12.0	13.0
Percentage elongation (%)	46.0	38.0	36.0	44.0	40.0	38.0
Ballistics						
Burning rate at 50 kg/cm^2 (mm/s)	7.2	7.5	7.8	7.3	7.5	7.8
Pressure index	0.31	0.31	0.31	0.31	0.31	0.31
Characteristic velocity C* (m/s)	1477	1462	1468	1453	1470	1462

(a) : Batch size 17 kg and mixer capacity 50 kg; (b) : mixing time 90 min and mixer capacity 25 kg

3.1 Mixing Time

Mixing durations of 60, 110 and 135 min were selected to evaluate the influence of mixing time on ballistics and mechanical properties of chosen nitramine-based propellant composition. Batch size in all the experiments was 17 kg. An increase in mixing time from 60 to 110 min resulted in about 44 per cent improvement in TS from 9 kg/cm^2. Propellants obtained after subjecting the ingredients to mixing for 135 min recorded a TS of 15 kg/cm^2. On the other hand, per cent elongation was reduced from 46 to 36 with an increase in mixing time. In the case of burning rate, there was an enhancement from 7.2 to 7.8 mm/s at 50 kg/cm^2 chamber pressure on increase in mixing time from 60 to 135 min.

3.2 Batch Size

In another set of experiments, the effect of scaling up on propellant characteristics was studied. Mixing time of 90 min was maintained for all the propellant batches. TS recorded for 8 kg batch was 10 kg/cm^2. It was 1.2 times for 17 kg batch. Further increase in batch size to 25 kg level led to a marginally higher TS (13 kg/cm^2). Scaling up from 8 to 25 kg batch size resulted in decrease in per cent elongation from 44 to 38. Burning rate recorded a marginal increase from 7.3 to 7.8 mm/s with an increase in batch size from 8 to 25 kg. The pressure index values remained almost same for all the batches.

Almost similar values for characteristic velocities further establish that there was no incidental variation in propellant composition in a given set of experiments.

These results bring out that an increase in mixing time and batch size lead to an increase in TS and burning rate. These observations are in line with the reported monotonical increase in burning rate and mechanical properties with increase in mixing time in case of AP-HTPB composite propellants[4]. In practice, the variables and factors associated with typical propellant processing are so many in number and so complex in interrelationship that several researchers have expressed the view that these may elude specified analysis. However, one of the factors generally attributed to the observed phenomenon is the continuous decrease in the mean particle size of the oxidiser particles which may be due to probable shattering of the particles upon blade impact as well as due to blade shearing action. It is hypothesised that the decrease in mean particle size of oxidisers depends upon the type of the crystal and crystal hardness. Other contributory factors may be the degree of dispersion of fine particles among coarse particles as well as the overall distribution of particulates in the propellant matrix[4].

Although extensive studies have been carried out in the field of combustion mechanism of propellants, there are few references available regarding the effect of processing variables on the combustion of propellants[5]. Ayerst[5] has pointed out that the surface reactions are most important from the point of view of overall burning rate. He has suggested that while NC-NG matrix may be assumed to be ballistically homogeneous, the inclusion of insoluble particulate solids (AP, RDX and *Al* in the present case) will mean that the criterion of homogeneity must depend upon the degree of dispersion of these solid materials. This will be applicable to non-homogeneous system like CP and CMDB propellants. Ayerst[5] has opined that in order to achieve maximum effects an even burning surface needs to be produced since an uneven surface will contain upstanding areas of low burning rate which will give a slower overall rate. Extent of gelatinisation of NC depending upon mixing time and batch size is also expected to have effect on mechanical properties and ballistics.

3.3 Combined Effect of Mixing Time and Batch Size

Ayerst[5] has proposed the concept of sphere of influence for ballistic modifiers in DBP which is based on the assumption that decomposition products may produce autocatalytic action on the matrix in a zone immediately surrounding the catalyst particles. He has suggested that high efficiency of a ballistic modifier may also be ensured if overlapping of spheres of influence occurs. In view of these observations, a third set of experiments was carried out on the selected composition ballistically modified by inclusion of 1.5 parts of basic lead salicylate (BLS) and 0.5 parts of carbon black and the combined effect of mixing time and batch size was studied with emphasis on changes in ballistics. Vertical mixer of 25 kg capacity was used for all the experiments (Table 2).

A combined increase in batch size from 5 to 17 kg level and mixing time from 55 to 85 min resulted in the enhancement in burning rate from 9.6 to 10.8 mm/s at 50 kg/cm^2 chamber pressure. At 65 kg/cm^2 chamber pressure, increase in burning rate recorded was of the order of 11 per cent. More or less similar trend was observed at a chamber pressure of 80 kg/cm^2.

Table 2. Combined effect of mixing time and batch size on the characteristics of ballistically modified CMDB propellant composition*

Property			Batch size (kg) 5 / Mixing time (min) 55	Batch size (kg) 17 / Mixing time (min) 85
Cal-Val (cal/g)			1126	1134
Density (g/cc)			1.64	1.64
Burning rate (mm/s)				
	Chamber Pressure			
	kg/cm^2	50	9.6	10.8
		65	11.2	12.4
		80	12.9	13.7
Pressure index				
	Pressure range			
	kg/cm^2	50-65	0.59	0.52
		65-80	0.68	0.48
		50-80	0.63	0.51
Characteristic velocity, C* (m/s)			1471	1481

* mixer capacity : 25 kg

This study brings out that mixing time and batch size are important factors from the point of view of overall propellant performance and will have a bearing on mission reliability.

4. CONCLUSIONS

In the case of AP- and RDX-based CMDB propellants, an increase in mixing time results in an increase in the TS and burning rate of the propellant. These findings are in line with those reported for AP-HTPB composite propellants. This phenomenon may be attributed to various factors like probable shattering of the oxidiser particles and overall distribution of solid particulates in the propellant matrix. Almost similar trend was observed with increase in batch size of propellants. In case of ballistically-modified CMDB composition, considerable increase in burning rate was observed due to combined effect of increase in mixing time and batch size. Previous findings in the case of double base propellants (DBP) reveal that the extent of uniformity in the distribution of ballistic modifiers determine their effectiveness.

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