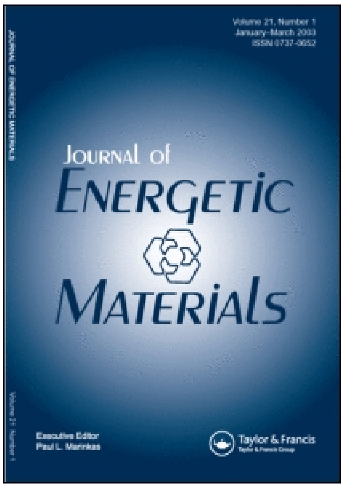


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# Studies on minimum signature nitramine based high energy propellant

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# STUDIES ON MINIMUM SIGNATURE NITRAMINE BASED HIGH ENERGY PROPELLANT

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## ABSTRACT

This paper reports the results on the influence of various metallic salts and metallic oxides on the ballistics of minimum signature nitramine based high energy propellants of practical value with stable combustion over a wide range of pressures. BLS was found to be an effective ballistic modifier individually as well as in combination with carbon black. Minimum signature composition containing 3:1:1 combination of BLS:$Cu_2O$:carbon black produced burning rate of 10.4 mm.s at 50 ksc pressure with temperature sensitivity of 0.3%/$^{o}$C. The Isp achieved was of the order of 232 s.

## INTRODUCTION

Minimum signature nitramine based high energy propellants are of great value for specific missions demanding higher energy (Isp) and low smoke level of exhaust gases[1]. Another distinct advantage of this class of propellants includes low vulnerability to ignition from such sources as spall of fragments[2]. However, major problems associated with pure nitramine based minimum signature propellants are poor ignitability, low burning rates and high pressure index ($\eta$) value[3]. These propellants are

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reported to resist ballistic modification[4]. We have earlier reported the results on the influence of BLS, LMDS and lead stannate on burning rates (strand burner) of CMDB compositions containing 20% RDX and 10% Al .None of the ballistic modifiers were found to be very effective in either enhancing burn rates or reducing '$\eta$' values[5].Fifer[6] has reviewed the work of various researchers on the ballistic modification of nitramine based propellant and drawn similar conclusions. Borohydrides are reported to catalyse nitramine based propellants, however, they pose compatibility and processing problems[5,6].

In view of above, during present study a minimum signature high energy propellant containing about 12% RDX was studied. Small quantity of AP (about 6%) was incorporated to obviate above referred problems to some extent[7]. Further, a small amount of Al (about 3%) was used as combustion instability suppressant[8]. The smoke level of this composition as determined by using a light source and photocell arrangement at nozzle end was found to be close to that of well known non-smoky double base propellant (DBP) systems.

During the course of present work influence of ballistic modifiers, effective in composite propellants (CP) and DBP namely,lead stannate, copper chromite, lead methylene disalicylate (LMDS), lead copper $\beta$ resorcylate salicylate, basic lead salicylate (BLS), metallic oxides (PbO, $Cu_2O$) and their combinations with or without carbon black (C-black), on ballistic characteristics was studied in 40-50 ksc range. Unlike previous studies the ballistic parameters were determined by statically firing propellant grains in 2 kg rocket motor instead of routine strand burner/acoustic bomb methods used normally. Of the various compositions studied, one promising composition was evaluated for burning rate, thrust and Isp over wide range of pressures (30-70 ksc) and for temperature/pressure sensitivity [$(\pi r)_p$ and $(\pi p)_k$] in the temperature region of -20 to +50°C. Results of cal-val and tensile strength (TS) are also discussed. An attempt has been made to understand the flame structure.



## EXPERIMENTAL

Propellant compositions with 79% DB matrix (spheroidal NC 42% and DEP desensitized NG 37%) were prepared by slurry cast technique as per the details described elsewhere[9]. Cal-val was determined using Julius Peters Bomb at loading density of 0.016 g/cc. BLS and LMDS were prepared at ERDL pilot plant and other ballistic modifiers were procured from trade. The purity of all the additives was minimum 98%.

For determination of TS, Instron Universal Testing Machine (Model 1185) was used. The dumbbell shaped specimens of 30 mm length, 4 mm width and 3 mm thickness were used.

Ballistic parameters were determined by static evaluation of propellant grains of 190 mm length, 110 mm OD, 76 mm ID and 1.6 kg weight in mild steel test motor after conditioning at ambient temperature (27°C) for 10 h. Pressure time (p-t) and thrust time (f-t) profiles were recorded using strain gauge and load cell in conjunction with Hewlitt Packard 9845 B model computer and data acquisition system. Venturies for test motor were adjusted for each composition to achieve desired chamber pressure range. Burning rates were computed from p-t profile. A typical output obtained is depicted in Fig. 1.

In order to assess temperature and pressure sensitivities, propellant grains were conditioned in cooling chamber and in ovens with temperature control accuracy of ± 0.5°C and then statically evaluated.



## RESULTS AND DISCUSSION

T.S. results given in Table 1 indicate that T.S. of all the compositions was in the range of 13-16 ksc, except in case of PbO based composition, which gave TS of 11 ksc. Composition containing metallic ballistic modifier recorded marginally lower cal-val (1075-1110 cal/g) than control (1120 cal/g). It can be seen from the results of static evaluation of control and compositions containing lead stannate, copper chromite and LMDS that these ballistic modifiers did not produce any significant catalytic activity. However, BLS was found to be the most effective ballistic modifier, as it increased the burning rates by 20% with respect to control, although the pressure index value remained more or less unaffected. Lead copper β resorcylate salicylate increased burn rate by 12-14% (Table 2).

Thus, lead salts reported to be very effective with DBP were found to be comparatively much less effective with nitramine based high energy DBP.

During second phase of the study compositions containing BLS in combination with varying proportions of C-black were evaluated. Results are given in Table 3. 1.5 parts BLS with 0.5 part of C-black gave superior ballistics with catalytic effect of 23 and 42% at 40 and 50 ksc chamber pressures respectively. Pressure index value of 0.48 was obtained for this composition. Observation that C-black is effective only upto a particular optimum level is in line with our earlier findings in case of DBP[10].

Results of 0.5 part of C-black alongwith metal oxides and their combinations with BLS are given in Table 4.

Among metallic oxides lead oxides (PbO) was found to be superior as ballistic modifier than Cuprous oxide ($Cu_2O$) and their combination was as effective as PbO alone.

Among the various combinations of BLS and metallic oxides, BLS+$Cu_2O$ had same effect as BLS+PbO for burning rate enhancement. In case of BLS+$Cu_2O$+PbO combination further enhancement of burning rate (28%) was obtained and '$\eta$' value was brought down. BLS along with PbO in 3:1 combination exhibited more or less similar behaviour. However, combination of BLS with $Cu_2O$ in the same proportion (3:1) showed the best catalytic effect It produced 40% increase in burn rate.

In view of these findings, BLS+$Cu_2O$ (3:1) combination was evaluated in minimum signature CMDB composition for burning rates, thrust and Isp in the pressure range of 30-90 ksc (Table 5). Thrust and Isp of the order of 3392 N and 221 s respectively were obtained at 50 ksc, which correspond to 4706 N thrust and 232 s Isp respectively at 70 ksc pressure.

Static evaluation of propellant grains conditioned at -20 and +50°C gave temperature sensitivity of burning rate ($\sigma_p$) and pressure ($\pi$)k as 0.3 and 0.7%/°C respectively (Table 6).

Nitramine based minimum signature propellants are reported to have flame structure similar to that of DBP comprising of foam, fizz, dark and luminous zones[11]. Yano and Kubota[12] have found that in case of HMX-CMDB propellant burning rate decreases on increase in nitramine concentration upto certain extent. They have attributed this phenomena to shift in the ratio of $NO_2$/aldehydes towards fuel rich leading to reduction in the reaction rate in the fizz zone on addition of nitramines to DBP.

As DBP matrix forms the major portion (about 80%) of minimum signature composition studied and nitramines are also expected to behave similarly, the mechanism of action of ballistic modifiers in DBP is expected to be operative in present case also. Carbon and carbonaceous matter formation theory explains most of the observed facts satisfactorily[13,14]

Typical flame structure of non-catalyzed minimum signature propellant recorded by high speed video camera in air is given in Fig.2. A considerably small dark zone was observed which may be attributed to the presence of AP in the composition. The ejection of carbonaceous particles which is an important characteristic of nitramine combustion was observed. In the catalyzed composition dark zone was almost non-existent and there was a remarkable increase in the flame brightness (Fig. 2). These observations are in line with those of Cohen Nir[3] and Kubota[11] et al, suggesting a substantial alteration in surface and sub surface zone chemistry.

## CONCLUSIONS

BLS was found to be a superior ballistic modifier as compared to metallic salts and oxides evaluated during our study for minimum signature CMDB propellant. 3:1 combination of BLS and C-black gave the best synergistic effect. Highest catalytic activity was exhibited by BLS:$Cu_2O$:c-black in 3:1:1 combination. The composition gave temperature sensitivity of burning rate 0.3%/$^{\circ}$C and pressure sensitivity of 0.6%. Isp achieved was 232 s Flame structure studies suggest alteration in surface and sub surface zone chemistry.

Table 1 : Cal-val and Tensile Strength of various compositions

| | | Cal-val (cal/g) | Tensile strength (ksc) |
|---|---|---|---|
| 1. | Control | 1120 | 13 |
| 2. | Lead stannate | 1101 | 13 |
| 3. | Copper chromite | 1106 | 14 |
| 4. | LMDS | 1075 | 14 |
| 5. | Lead copper β resorcylate salicylate | 1108 | 13 |
| 6. | BLS | 1111 | 13 |
| 7. | BLS-1.75: C/black-0.25 | 1136 | 15 |
| 8. | BLS-1.5: C/black-0.5 | 1144 | 15 |
| 9. | BLS-1.25: C/black-0.75 | 1112 | 14 |
| 10. | PbO-1.5: C/black-0.5 | 1159 | 11 |
| 11. | $Cu_2O$-1.5: PbO-1.5: C/black-0.5 | 1140 | 14 |
| 12. | $Cu_2O$: -0.75: PbO-0.75: C/black-0.5 | 1151 | 14 |
| 13. | BLS-0.75: PbO-0.75: C/black-0.5 | 1149 | 15 |
| 14. | BLS-0.75: $Cu_2O$-0.75: C/black-0.5 | 1143 | 15 |
| 15. | BLS-0.5: $Cu_2O$-0.5: C/Black-0.5 | 1154 | 16 |
| 16. | BLS-1.0: PbO-0.5: C/black-0.5 | 1170 | 15 |
| 17. | BLS-1.0: $Cu_2O$-0.5: C/black-0.5 | 1148 | 17 |

**Table 2 : Influence of Lead Stannate, Copper Chromite and Metal Salts on Ballistics of Minimum Signature CMDB Composition**

| Ballistic Modifier 2 parts | Burning rate at ksc mm/s 40 | 50 | % Catalytic effect at ksc 40 | 50 | Pressure index in pressure range 40-50 ksc |
|---|---|---|---|---|---|
| Control | 6.8 | 7.4 | - | - | 0.35 |
| Lead Stannate | 7.1 | 7.8 | 4 | 5 | 0.43 |
| Copper chromite | 7.0 | 7.8 | 3 | 5 | 0.47 |
| LMDS | 6.9 | 7.9 | 2 | 7 | 0.58 |
| Lead copper $\beta$ resorcylate salicylate | 7.6 | 8.4 | 12 | 14 | 0.44 |
| BLS | 8.1 | 8.8 | 19 | 19 | 0.34 |

**Table 3 : Effect of various BLS and Carbon black proportion on ballistics of nitramine based minimum signature composition**

| Ballistic Modifier 2 parts | Burning rate at ksc mm/s | | % Catalytic effect at ksc | | Pressure index in pressure range 40-50 ksc |
|---|---|---|---|---|---|
| | 40 | 50 | 40 | 50 | |
| Control | 6.8 | 7.4 | - | - | 0.35 |
| BLS | 8.1 | 8.8 | 19 | 19 | 0.34 |
| BLS-1.75+C/balck-0.25 | 8.1 | 8.8 | 19 | 19 | 0.37 |
| BLS-1.5+C/black-0.5 | 8.8 | 9.8 | 29 | 32 | 0.48 |
| BLS-1.25+C/black-0.75 | 8.3 | 9.3 | 22 | 26 | 0.53 |

**Table 4 : Influence of metallic oxides on combustion behaviour of minimum signature CMDB Composition**

| Ballistic Modifier 1.5 parts + 0.5 parts C/black | Burning rate at ksc mm/s 40 | 50 | % Catalytic effect at ksc 40 | 50 | Pressure index in pressure range 40-50 ksc |
|---|---|---|---|---|---|
| Control | 6.8 | 7.4 | - | - | 0.35 |
| $Cu_2O$ | 6.9 | 9.1 | 2 | 23 | 1.2 |
| PbO | 8.4 | 9.2 | 24 | 24 | 0.38 |
| $Cu_2O$+PbO (1:1) | 8.4 | 9.3 | 24 | 24 | 0.49 |

**Table 5 : Results of BLS and Metallic oxide combination on ballistics of minimum signature CMDB Composition**

| Ballistic Modifier 1.5 parts + 0.5 part C/Black | Burning rate at ksc mm/s 40 | 50 | % Catalytic effect at ksc 40 | 50 | Pressure index in pressure range 40-50 ksc |
|---|---|---|---|---|---|
| Control | 6.8 | 7.4 | - | - | 0.35 |
| BLS+$Cu_2O$ (1:1) | 7.5 | 9.4 | 10 | 27 | 1.00 |
| BLS+PbO (1:1) | 7.9 | 9.1 | 16 | 23 | 0.63 |
| BLS+$Cu_2O$+PbO (1:1:1) | 8.7 | 9.5 | 28 | 28 | 0.46 |
| BLS+$Cu_2O$ (3:1) | 9.5 | 10.4 | 40 | 41 | 0.42 |
| BLS+PbO (3:1) | 8.3 | 9.3 | 22 | 26 | 0.51 |

**Table 6 : Results of Burn rate and Isp of minimum signature composition containing 1.5 part BLS, 0.5 part $Cu_2O$ and 0.5 part C/Black**

| Chamber Pressure ksc | Burning rate mm/s | Thrust kg | Isp s |
|---|---|---|---|
| 30 | -- | --- | --- |
| 40 | 9.5 | 305 | 215 |
| 50 | 10.4 | 397 | 221 |
| 60 | 11.2 | 480 | 226 |
| 70 | 12.5 | 572 | 232 |

**Table 7 : Temperature sensitivity of BLS, $Cu_2O$ and C/Black (3:1:1) based nitramine propellant composition**

| Conditioning temperature deg. C | Burning rate at 50 ksc mm/s | Temperature sensitivity of burning rate ($\sigma_p$) %/°C | Average pressure | Temperature sensitivity of pressure $(\pi)_k$, %/°C |
|---|---|---|---|---|
| - 20 | 9 | 0.3 | 40 | 0.7 |
| + 27 | 10.4 | | 56 | |
| + 50 | 11.2 | | 66 | |

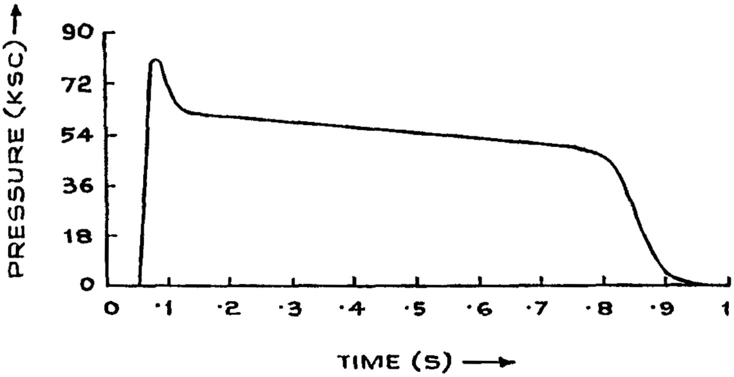


FIG.1: A TYPICAL PRESSURE TIME PROFILE

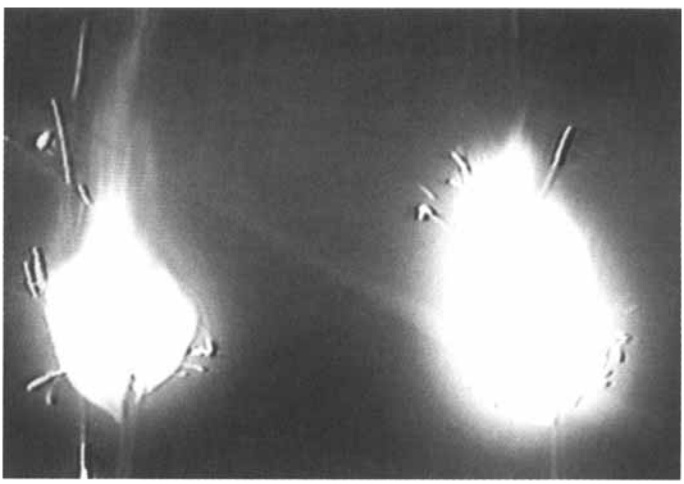

FIG 2

FLAME STRUCTURE OF UNCATALYZED AND CATALYZED MINIMUM SIGNATURE NITRAMINE BASED HIGH ENERGY PROPELLANTS

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