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Burning Rate Characteristics of *Mg-NaNO₃* Propellants

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ABSTRACT

The combustion phenomena of Mg-$NaNO_3$ propellants have been studied. Results of burning rate at different mixture ratios and particle sizes indicate that the compositions containing finer particle size (50 μm) $NaNO_3$ give higher burning rate at high fuel content of the mixture than at the stoichiometric ratio; whereas the compositions with coarser particle size (250 μm) $NaNO_3$ show increased burning rate with increasing oxidiser content and give a maximum at stoichiometric point. Thermal decomposition results indicate that the condensed phase heat release at the propellant surface and the reactions in the vapour phase are responsible for variations in the burning rate. The decomposition products of finer size $NaNO_3$, react with *Mg* before *Mg* particles acquire sufficient energy for ignition, and lead to condensed phase heat release. This heat is maximum at high fuel content and causes high burning rate with low pressure and temperature sensitivity. The increase in the oxidiser content reduces the condensed phase heat due to formation of metal agglomerates and causes lower burning rate with high pressure and temperature sensitivity. After the *Mg* particles acquire sufficient energy for ignition the decomposition products of coarser size $NaNO_3$ diffuse out along with *Mg* and react in the vapour phase. This causes an increase of burning rate with increase in the oxidiser content of the mixture up to the stoichiometric ratio with a pressure and temperature dependence.

1. INTRODUCTION

Thermochemical evaluation of combustion properties of magnesium as a fuel candidate for solid fuel ramjet system exhibits remarkable performance of utilisation of energy in comparison to the commonly used hydrocarbon fuels due to its high combustion efficiency[1,2]. Inspite of the promising potential of Mg-$NaNO_3$ propellants, the practical use of this mixture presents severe problems of complex burning phenomenon which have major effects on the energy generation process within the combustor. Although a few studies have been reported on the combustion of this type of propellant system[3,4], a well-defined mechanism is not available.

In the present work, experiments were carried out on Mg-$NaNO_3$ propellants at different mixture ratios and particle sizes to determine the physico-chemical parameters controlling the burning rate characteristics. Attempts have been made to evolve a suitable combustion mechanism to explain the results obtained.

2. EXPERIMENTAL

To determine the burning rate characteristics, Mg-$NaNO_3$ propellant grains of 100 mm dia and 200 mm length were processed by pressure moulding using the Mg-$NaNO_3$ compositions of different mixture ratios and particle sizes. Samples for measurement of heat of combustion were prepared in the form of 10 mm dia pellets by compacting to the same density level. Samples for thermal decomposition studies were taken from the pellets.

Burning rates of the propellant at different chamber pressures were determined in a test motor of 114 mm dia by static firing. The different chamber pressures

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during the static tests were achieved by changing the throat area of the test motor. To test the propellant at different temperatures, the propellants were conditioned at – 40 °C and +50 °C for 24 hr and static-tested. Heat of combustion was evaluated with an adiabatic bomb calorimeter. Thermal decomposition of the samples was measured using differential thermal analyser (DTA).

3. RESULTS AND DISCUSSION

Burning rates of *Mg*-$NaNO_3$ propellants at different mixture ratios and particle sizes were determined. The presence of finer size *Mg* particles (50 μm) increased the burning rate at all mixture ratios and pressures. This is due to the increased surface area which results in higher thermal conductivity compared to the coarser *Mg* particles.

When finer size $NaNO_3$ (50 μm) was present in the composition, burning rate was maximum at 30 per cent $NaNO_3$ content and reached a low value at the stoichiometric point (58 per cent $NaNO_3$). With coarser size $NaNO_3$ (250 μm), the burning rate increased continuously with the increased $NaNO_3$ content and showed a maximum at the stoichiometric point.

The effect of particle size of $NaNO_3$ on the burning rate of *Mg*-$NaNO_3$ propellants at 70:30 and 40:60 mixture ratios at different pressures is shown in Fig. 1 (see Table 1 for details). It is seen that with finer size

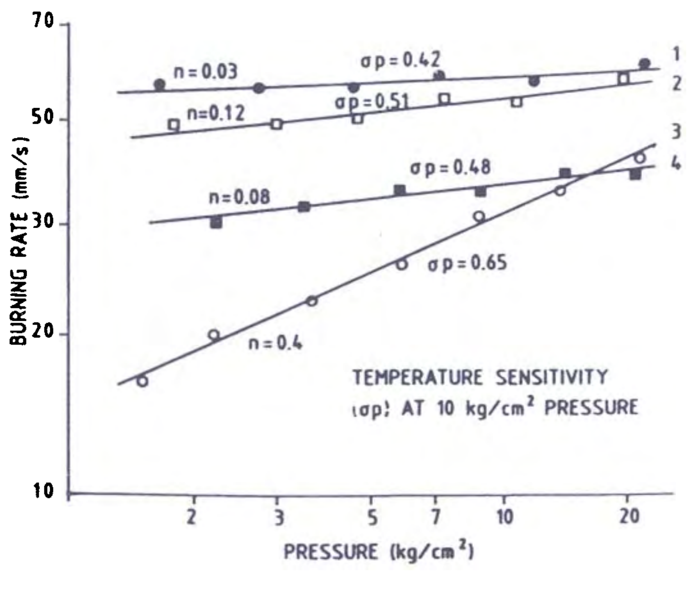

Figure 1. Burning rate of *Mg*-$NaNO_3$ propellants as a function of pressure.

Table 1

	Curve number							
	1		2		3		4	
	(a)		(a)	(b)	(a)	(b)	(a)	(b)
Mg	50	70	50	40	50	70	50	40
$NaNO_3$	50	30	50	60	250	30	250	60

a : particle size (μm) ; b : mix ratio (%)

$NaNO_3$ burning rate is maximum at the 70:30 ratio and increases marginally with the increase in pressure, while at the 40:60 ratio the burning rate has a lower value and increases rapidly with the rise in pressure. On the other hand, coarser $NaNO_3$ gives burning rates in between those for the finer $NaNO_3$ compositions and shows a lower value at the 70:30 ratio. The pressure exponent (n) and the temperature sensitivity (σ_p) of the burning rate defined by $n = d(\ln r)/d(\ln p)$ and $\sigma_p = d(\ln r)/dT_0$ are respectively found to be higher with stoichiometric composition than the fuel-rich composition.

The heat of combustion data showed that heat energy gradually increases up to the stoichiometric point irrespective of the particle sizes of the ingredients. This shows that the energetics have an increased trend when the ratio of the composition approaches the stoichiometric value, whereas the burning rate varies depending on the mixture ratio and particle size of the ingredients.

Thermal decomposition studies of *Mg*-$NaNO_3$ propellants with finer size $NaNO_3$ indicate two exotherms, one at 460 °C and the other at 465 °C with *Mg*-$NaNO_3$ at 70:30 ratio and at 523 °C with *Mg*-$NaNO_3$ at 40:60 ratio (Fig. 2). The exotherm at 460 °C can be accounted for the surface oxidation of the mixture of *Mg* and $NaNO_3$. The second exotherm can be accounted for the total ignition of the sample. In the presence of coarser particle size $NaNO_3$, a single exotherm at 545 °C with *Mg*-$NaNO_3$ at 70:30 ratio and at 570 °C with *Mg*-$NaNO_3$ at the 40:60 ratio, is indicated. It is further seen that at the 40:60 ratio although the ignition occurs at higher temperature, the heat evolution in the exotherm increases, in contrast to the behaviour seen with the composition containing finer size $NaNO_3$.

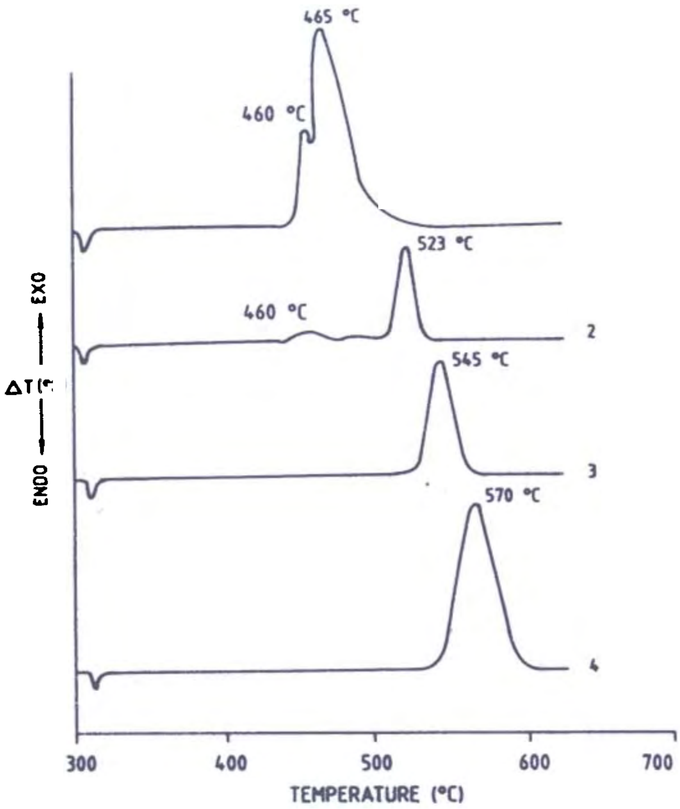

Figure 2. DTA data of Mg-$NaNO_3$ propellants.

The exotherm at 460 °C in the thermal decomposition with the finer size $NaNO_3$ compositions indicates that there is a significant interplay between the oxidiser decomposition products and self heated *Mg* particles leading to condensed phase heat release before the *Mg* particles acquire sufficient energy for ignition. This heat is responsible for further decomposition of the oxidiser species in the solid phase and also for the ejection of metal particles from the surface to the flame zone and may be leading to total ignition. Hence the heat release in the condensed phase has a predominant role in the combustion of Mg-$NaNO_3$ propellants in presence[5] of finer size $NaNO_3$.

The large release of condensed phase heat explains the high burning rate with Mg-$NaNO_3$ at the 70:30 ratio. At this ratio since the combustion is highly dependent on the condensed phase heat release, there may not be much change expected in the burning rate of the propellant with a change of pressure and temperature. Higher concentrations of finer particle size $NaNO_3$ beyond 30 per cent leads to a thicker oxide coating of the metal particles with high concentration of molten oxidiser. This reduces the condensed phase heat release followed by the formation of metal agglomerates which may cause diffusion of the oxidiser species to the flame zone without accompanying *Mg* particles, resulting in inefficient burning and reduced burning rate. At this stage of combustion, the change of pressure and the propellant initial temperature may change the degree of metal agglomeration and lead to variations in the condensed phase heat release and reaction zone temperature. This causes for change in the burning rate with high pressure and temperature sensitivity of the propellant.

The decomposition of coarser size $NaNO_3$ (545 °C) occurs after the *Mg* particles attain sufficient energy for ignition and causes the absence of condensed phase reactions (Fig. 2). The presence of a single exotherm at higher temperature suggests total ignition of the sample in the vapour phase. This heat then conducts to the burning surface for further regression of the propellant which explains why the burning rate increases as the proportion of the oxidiser of coarser particle size increases up to stoichiometric ratio. The lower heat release in the vapour phase at high fuel content of the mixture explains the lower burning rate with a pressure and temperature sensitivity. The inorease in the concentration of the oxidiser increases both the metal agglomeration and the flame zone temperature, because the combustion of *Mg* agglomerates in presence of sufficient oxidiser species occurs more efficiently than for stoichiometric compositions with the finer size $NaNO_3$. Any rise of pressure and propellant initial temperature increases the burning rate since the higher pressure moves the flame zone closer to the burning surface and thus increases the surface temperature gradient.

4. CONCLUSION

Based on the present study, the following conclusions can be drawn:

(a) Burning rate characteristics of Mg-$NaNO_3$ propellant are dependent on the mixture ratio and the particle size of the ingredients. Decomposition products of finer particle size $NaNO_3$ (passing 200 BSS) in Mg-$NaNO_3$ propellant react with *Mg* particles in condensed phase and release condensed phase heat, leading to high burning rate at high fuel content with low pressure and temperature sensitivity. However, at stoichiometric ratio, metal agglomerates are formed and the reactions become inefficient resulting in low burning rate.

(b) The presence of coarser particle size $NaNO_3$ (24-60 BSS) in the mixture shifts the reactions to the vapour phase where its decomposition products react with the ejected *Mg* particles. This causes increase in the burning rate and pressure and temperature sensitivity with increasing oxidiser content and provides efficient combustion at stoichiometric ratio.

(c) Finer particles of *Mg* increases the burning rate at all mixture ratios of Mg-$NaNO_3$ propellants due to the increase in the surface area of the metal particles.

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