Effect of Aluminium in Propellant Composition on Acoustic Emission Parameters

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ABSTRACT

The study reports the variation in acoustic emission signals acquired during combustion of typical propellants with varying aluminium and ammonium perchlorate content. It was observed that when propellant strands having the same composition undergo combustion under similar conditions, they produce consistent acoustic emission signals. To study the effect of variation of aluminium content in the propellant composition on the acoustic emission produced during combustion, the aluminium content was varied from 6 per cent to 18 per cent in a HTPB-based composite propellant with 86 per cent solid loading. Experiments were carried out with propellant strands under the same conditions for a comparative study. Acoustic emission parameters, such as peak amplitude, ring-down counts, average frequency, hits and energy were studied as functions of time. Among these parameters, only energy ring-down counts and frequency varied significantly with aluminium content. The effect of cumulative values of energy, frequency and ring-down counts, the effect of burn rate and theoretical specific impulse against the aluminium percentage variation, and the variation of specific impulse against acoustic energy can all be correlated. The clear trend is indicative of possible prediction of propellant performance parameter like specific impulse from acoustic emission parameters.

Keywords: Propellant combustion, acoustic emission signals, acoustic emission parameters

1. INTRODUCTION

Acoustic emission activity consists of stress wave travelling through or along a solid elastic material, a liquid or a gas. These transient elastic waves are generated due to rapid release of strain energy from localised sources within a material. In other words, acoustic emission refers to the stress waves generated by the dynamic processes in materials. Generally, these waves are the result of either internally generated or externally applied mechanical or thermal stresses. The term event is used for the occurrence of a discrete acoustic emission generated by a single source. Each discrete emission event appears as a wave packet (burst) that initially increases, reaches one or more peak amplitudes and then decreases. Usually, piezoelectric sensors are used to convert the acoustic emission stress waves into electric signals that are amplified and further processed. The term hit is used for the wave packets that are received by multiple independent channels.

Koury[1] and Christensen[2] reported motor burning rate prediction using acoustic emission strand burn rate technique. Caveny[3], *et al.* reported burn rate variations of nitrocellulose-based propellant at higher pressures using combustion-generated acoustic emissions. Bell[4], *et al.* have shown that acoustic emissions have a potential use,

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both as diagnostics of combustion and a mean for the study of fundamental burning process. Effect of atmosphere in which the propellant is burnt, ammonium perchlorate (AP) particle size, aluminium addition, and aluminium coating in HTPB-AP-based propellants have been reported. Evaluation of burn rate using acoustic emission technique has been reported by several workers[5-8].

There are several ways to process acoustic emission signals. Most of these measure the characteristics of the individual burst emission and all can give useful information in an acoustic emission experiment. The aim of signal processing and display is to identify the character and significance of the event. The common ways of signal processing are:

(a) Ring-down count analysis

(b) Energy analysis

(c) Peak amplitude distribution analysis

(d) Frequency analysis

(e) Event duration analysis.

When applying acoustic emission to propellant combustion, the primary observations is concerned with the ultrahigh frequency acoustic emission generated by the combustion process. The combustion-generated ultrahigh frequency acoustic emission sensed by an acoustic emission transducer can then be processed.

The present study reports the variation in acoustic emission waves generated during propellant combustion with varying compositions. Based on the previous work[6,7], it has been observed that when propellant strands having the same composition undergo combustion under similar conditions, they produce consistent acoustic emission signals. The aim is to study the effect of varying the aluminium content in propellant composition on the acoustic emission produced during combustion of propellants. The technique consists of analysing the acoustic emission hitting the sensor during deflagration of solid propellant and relating the time domain parameters to the specific composition of the propellant.

2. EXPERIMENTAL SETUP

The materials used during the process are:

2.1 Materials

HTPB propellant → HTPB + *Al* + AP + DOA + Antioxidant + TDI + Cross-linker

2.2 Equipment

The equipment required are: Laboratory sigma mixer, vacuum casting unit, and curing oven. The burn rate setup consists of (i) a pressure vessel (1 l) having a sample holder and cap, and provisions for gas inlet and outlet, (ii) a manifold arrangement to connect the pressure vessel and nitrogen cylinders for pressurisation, (iii) a pressure monitoring system, and (iv) an ignition unit and fuse wire. It has an acoustic emission system consisting of (i) piezoelectric transducers (model-R15, resonant frequency 150 kHz, range 50 kHz to 600 kHz), (ii) an acoustic emission pre-amplifier (gain 40 dB) and frequency response range 100 kHz to 400 kHz, (iii) acoustic emission data acquisition board AEDSP-32/16, (iv) MISTRAS-2001 software by Physical Acoustic Ltd, UK, and (v) a microprocessor.

3. EXPERIMENTAL PROCEDURE

Mixing was carried out using a standard composition as the base, but varying the aluminium content from a minimum of 6 per cent to 18 per cent. The various mixing compositions are shown in Table 1. The propellant slurry was then vacuum-cast and cured in the oven at 60 °C for five days. The cured propellant was then cut into strands of 6 mm × 6 mm × 85 mm. The burning rate of the strands was measured as per standard procedure[6,8].

Table 1. Propellant compositions [solids (AP + *Al*): 86 per cent, binder: 14 per cent, AP(C): APC(F) = 4:1]

Composition No.	AP(C:F::4:1) (%)	Aluminium (%)
1	80	6
2	77	9
3	74	12
4	71	15
5	68	18

Table 2. Comparison of specific impulse with the acoustic properties for various compositions

Percentage of aluminium in propellant	Specific impulse at 70 ksc (s)	Acoustic energy (Cum. value) $\times 10^5$	Peak amplitude (Cum. value) (dB) $\times 10^5$	Average frequency (Cum. value) (kHz) $\times 10^5$	Ring-down counts (Cum. value) $\times 10^5$	Burn rate at 40 ksc (mm/s)
6	256.6	3.70	0.455	0.98	16.2	6.1
9	259.5	3.37	0.460	0.93	15.5	6.0
12	261.9	2.86	0.455	0.80	13.4	6.0
15	263.7	2.71	0.478	0.74	12.6	5.8
18	265.0	2.20	0.450	0.52	8.8	5.5

For comparative study, experiments were carried out with strands having different compositions under same pressure. Two strands of the same composition were ignited to ensure consistency of the results. The acoustic emission results of the tests have been obtained as a set of six individual graphs plotted. These graphs are:

(a) Peak amplitude versus time

(b) Ring-down counts versus time

(c) Average frequency versus time

(d) Hits versus time

(e) Energy versus time

(f) Average signal level (dB) versus time.

It has been observed that only three properties, i.e., energy, ring-down counts and average frequency varied significantly during a single-channel monitoring of propellant deflagration. Point plots as well as cumulative plots of various properties plotted against time were considered for analyses. Point plots were used to identify the range of variation, while the value from the cumulative plots was used to arrive at a characteristic value for each composition. The specific impulse values for different propellant samples were theoretically computed.

4. RESULTS & DISCUSSION

The acoustic emission results obtained from the sample have been analysed and presented in Table 2. It may be noted that the raw acoustic emission signal obtained from the test undergoes amplification analogue-to-digital conversion and related processing in the acoustic emission system. The dominant signal characteristics, such as peak amplitude, ring-down counts, average frequency, signal energy, average signal level, etc. are extracted from the signal and plotted as correlation/history plots.

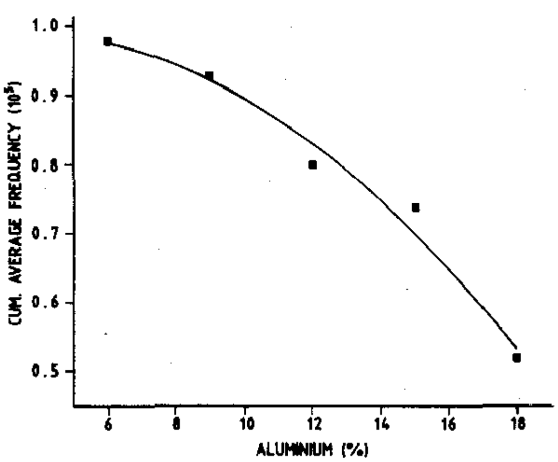

Figure 1(a). Cumulative average frequency versus aluminium percentage.

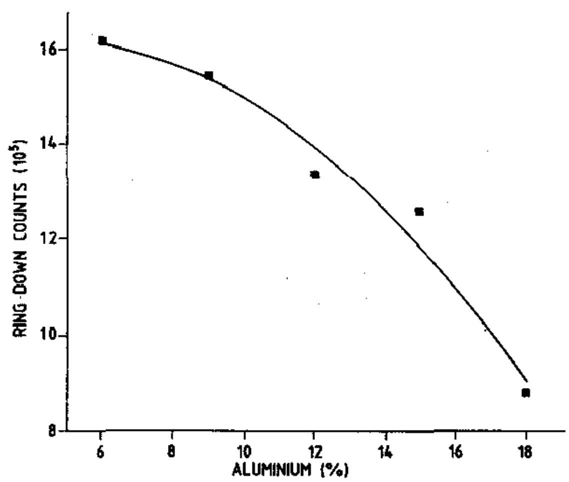

Figure 1(b). Ring-down counts versus aluminium percentage

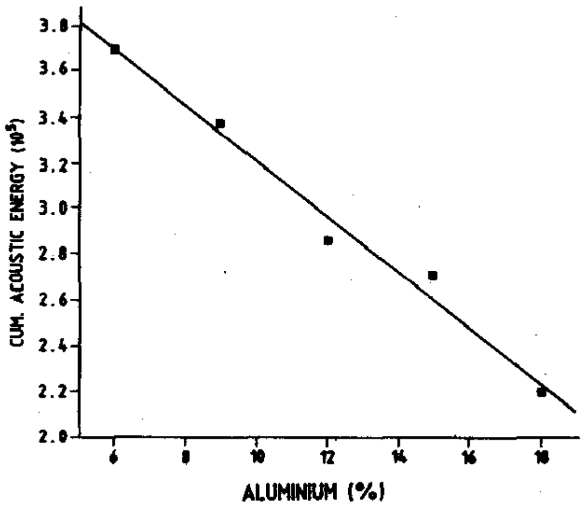

Figure 1(c). Cumulative acoustic energy versus aluminium percentage.

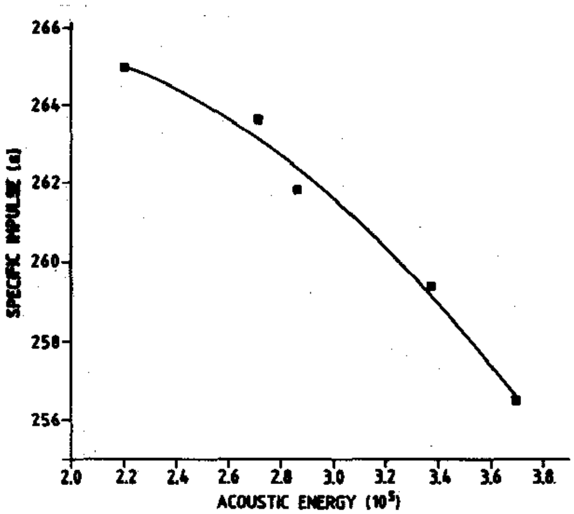

Figure 2. Specific impulse versus acoustic energy for varying aluminium compositions.

The cumulative values as well as range of acoustic energy, ring-down counts, average frequency and peak amplitude for different propellant compositions have been quantified. A clear trend in the variation of propellant combustion acoustic properties with the change in compositions of propellant can be observed. Figs 1(a), 1(b), and 1(c), reveal that as the proportion of aluminium in the propellant increases (corresponding to a decrease in percentage of AP), the cumulative values of acoustic energy, ring-down counts and average frequency decreases. The variation in the range of peak amplitude, however, is very small and its cumulative value does not show any clear trend. The theoretical specific impulse of the propellant increases and the observed burning rate decreases as the proportion of aluminium in it increases. The acoustic properties inclusive of acoustic energy exhibit a converse behaviour. Curve fitting techniques were used to arrive at an empirical polynomial relation between acoustic energy and specific impulse (given below) and presented in Fig. 2:

$$Y = 260.763 + 6.415x - 2.033x^2$$

5. CONCLUSIONS

Once the acoustic emission parameters are determined in a strand burn test, combustion properties like burn rate and specific impulse can be predicted within reasonable accuracy for preliminary screening of propellant formulations in a given system. Further, the acoustic parameters could be evaluated for preliminary screening of various formulations for any specific developmental propellant.

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