

Burning rate measurement of composite propellant using acoustic wave emission in comparison with other techniques

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Abstract

The burning rate of rocket propellants is one of the most important parameters having a direct influence on its ballistic characteristics, so accurate measurement of this parameter is an active approach for achieving optimum design of the solid rocket motors. In this paper, acoustic emission technique was applied for measuring the burning rate of a composite propellant and tests were performed on a wide Pressure range (5 - 9 MPa) at ambient temperature. 3 % as a deviation co-efficient of acoustic emission technique was investigated by comparing the burning rate results obtained by this technique and those obtained by actual burning of a small-scale test motors at 6.894 MPa (1000 PSI) and curves obtained from previously mentioned techniques were analyzed. This paper reports that the acoustic emission technique is a simple, effective, economic, time-saving, reliable technique with a high accuracy nearly equivalent to the active field results and it is suitable for quality control of large-scale productions of composite propellant.

I. INTRODUCTION

The burning rate is a mainly characteristic parameter controlling the ballistic behavior of the solid rocket propellants and it is an operative factor for assessment the efficiency of the overall rocket motor design^[1-3]. The burning rate of rocket propellants is subject to an exponential relation so it must be controlled throughout the burning period to avoid catastrophic rise in chamber pressure or abnormal, interrupted, unstable burning or chuffing phenomenon^[4]. Common factors affecting the burning rate are the combustion chamber pressure, the

initial temperature of the propellant grain, the composition of the propellant including mainly level and particle size of both oxidizers and burning rate modifiers^[5-7], grain geometry, erosive burning and motor vibration^[8,9].

Depending on phenomenon combined with propellant burning shown in Figure 1 many techniques have been introduced and developed till now shown in Table 1.

Smooth scaling-up from strand burner to sub-scale motor then to full-scale one with high accurate measurement of burning rate is the most critical challenge of rocket propellant industry {Formatting Citation}.

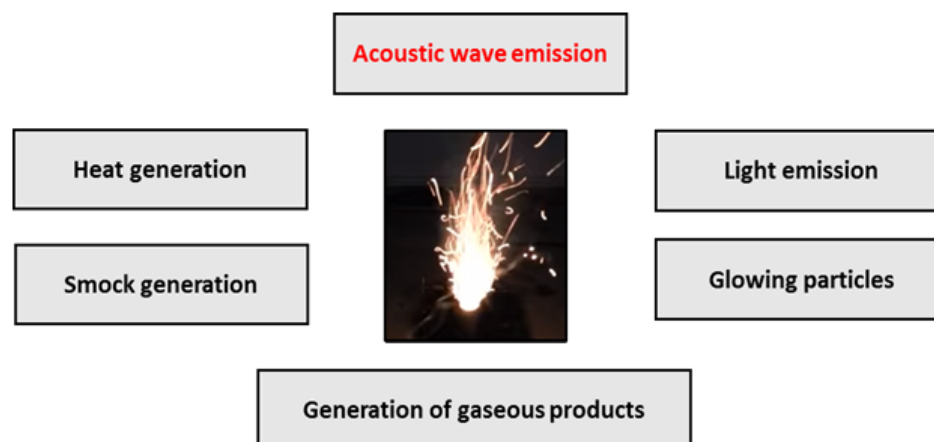


Fig. 1: Accompanying aspects to propellant burning process

Table 1: Briefed survey on propellant burning rate measurement techniques.

Year	Author	Technique	Principle	Ref.
1974	B.L. Crawford	Strand burner with Impeded wires	Electrical measurement of time interval for end-burning powder strand with predetermined length.	[11]
1998	Desh. Deepak	Ultrasonic pulse-echo technique.	Emitting of ultrasonic wave and travels in the propellant itself and reflected at the surface of the propellant then return back to the transducer.	[12]
1962	D.L. Johnson	Microwave technique	Continuous measure for the shift of the phase in the reflected signal from the propellant burning surface.	[13]
1963	J. R. Osborn	High speed camera	Recording the burning process of the material and the rate of burning usually obtained by the determination of the burned thickness through the selected time interval.	[14]
1977	L.H. Caveny	Acoustic Emission	Timing the period of acoustic wave emission during burning of propellant strip underwater.	[15]

II. Experimental

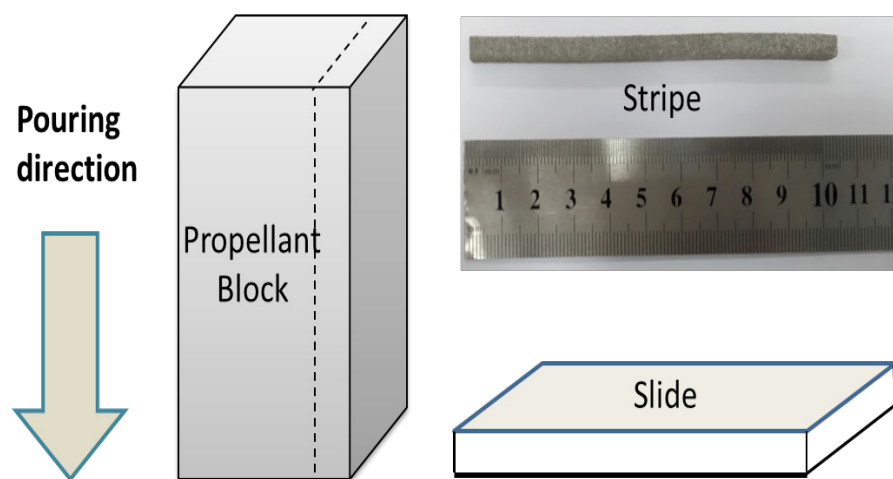
II.1 Formulation and raw materials

Aluminized Propellant composition has 86% solid fillers and 14% binder with 0.9 curing ratio(NCO/OH) were prepared by the cast technique. The propellant composition contains 69% Ammonium perchlorate (AP), 17% Aluminum and 14% polyurethane matrix. The formulation was prepared in a vertical mixer and cured for certain time in oven. AP was dried at 85 0C for 48 hours. The binder matrix contains hydroxyl terminated polybutadiene (HTPB), hexa-methylene diisocyanate (HMDI), dioctyl adipate (DOA) and Tris-1- (2, Methyl Aziridiny) Phosphine Oxide (MAPO). At first, the ingredients of the binder (HTPB-DOA-MAPO) have been premixed under stirring of 150 rpm at 60 0C for 10 min.,

accompanied by inserting the Al fuel under mixing for 15 min. Then addition of AP takes place under continuous stirring for another 15 min. lastly, HMDI (curing agent) has been added to the previous mixture at 400C and left under stirring for 15 min on vacuum for degassing. The freshly prepared slurry was casted into three standard 2-inch test motor and one mold for propellant bulk production. Finally curing process takes place at 500C for 6 days.

II.2 Sample preparation

The completely cured blocks of composite propellants must be without any cracks. The grain must be prepared using pneumatic grain cutter. Samples have to be placed in a pouring direction firstly cut 5mm thickness of the block skin. The dimensions are required as follow: width 6mm, thickness 6mm and length 120mm (Figure 2).

**Fig. 2:** Methodology of sample preparation.

II.3 Instrumentation

The previously prepared composite solid propellant stripes were put into water-filled combustion chamber after fixing it in sample holder with the aid of (30 SWG) Ni-Cr wire as shown in Figure 4(b).

The combustion chamber is pressurized with different values of nitrogen from 5 to 9MPa and the operating temperature is adjusted by thermostat water channel as normal condition (25°C). As soon as electrically started ignition process with (18 V and 2 Amp current) takes place the burning starts from up to down and the acoustic wave starts to be emitted throughout the sample burning period^[16-19].

The continuous acoustic emission signals, which

created by specimen during burning, transferred through combustion chamber and received by sensor (350 kHz resonance acoustic transducer), have converted into electric signals, they are amplified by preamplifier and sent to data acquisitions system for calculation Figure 3. The time counter is stopped when the specimen burning is over. The burning rate at each certain pressure is calculated by the basic equation Eq. (1):

At which: is the specimen length of sample (mm) and is calculated time of burning (s).

$$r = \frac{L}{\Delta t} \quad (1)$$

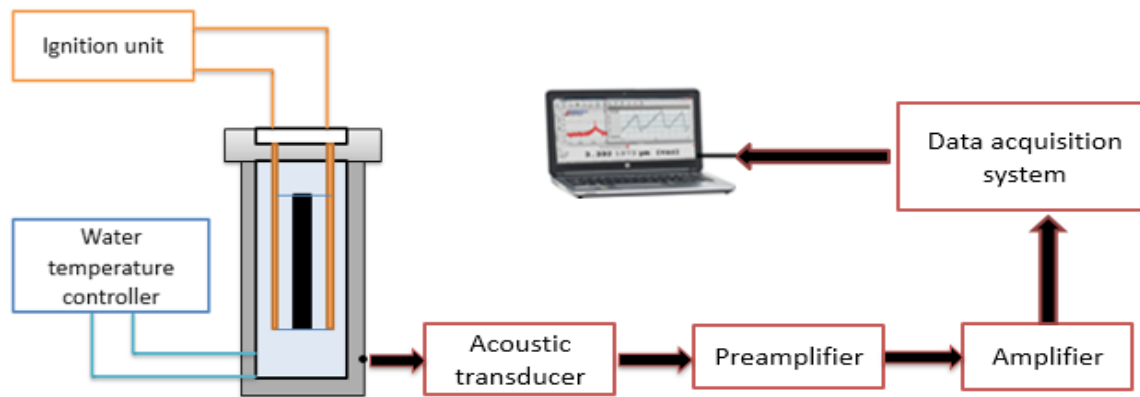


Fig. 3: Acoustic wave emission integrated system.

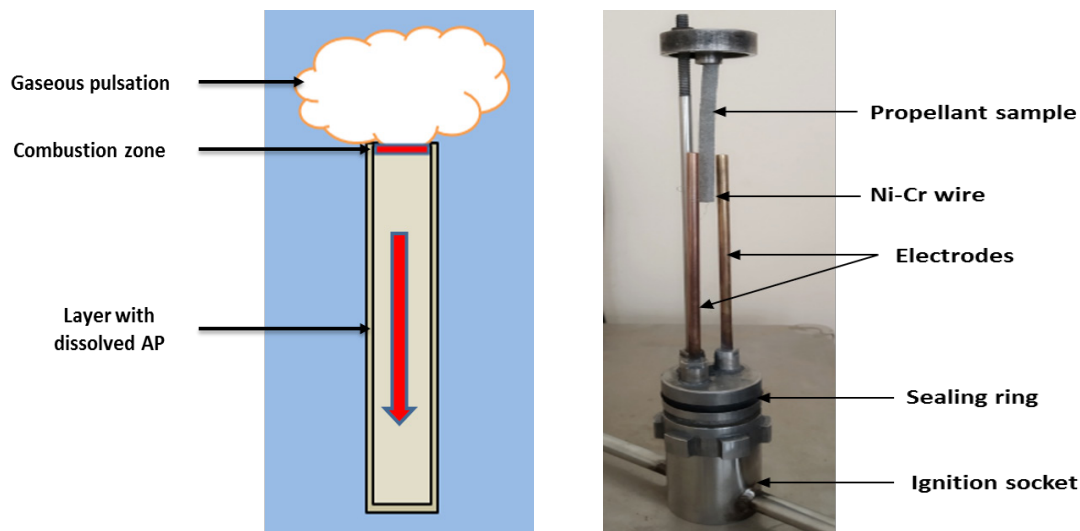


Fig. 4: (a) Pulsation prefigure and (b) Specimen fixation methodology.

On the another hand, small scale test motors as shown in Figure 5 were prepared with different throat diameters as 7 , 7.3 , 7.6 mm respectively achieving different operating pressures and as a result different burning rates^[17-20].

The tested rocket motors were put onto function using

igniter at 25°C. The operating pressures were measured via special pressure transducers with two channels converting the pressure into electric signals which processed by special data acquisition system and the ballistic parameters were successfully plotted on the pressure-time curve Figure 6.

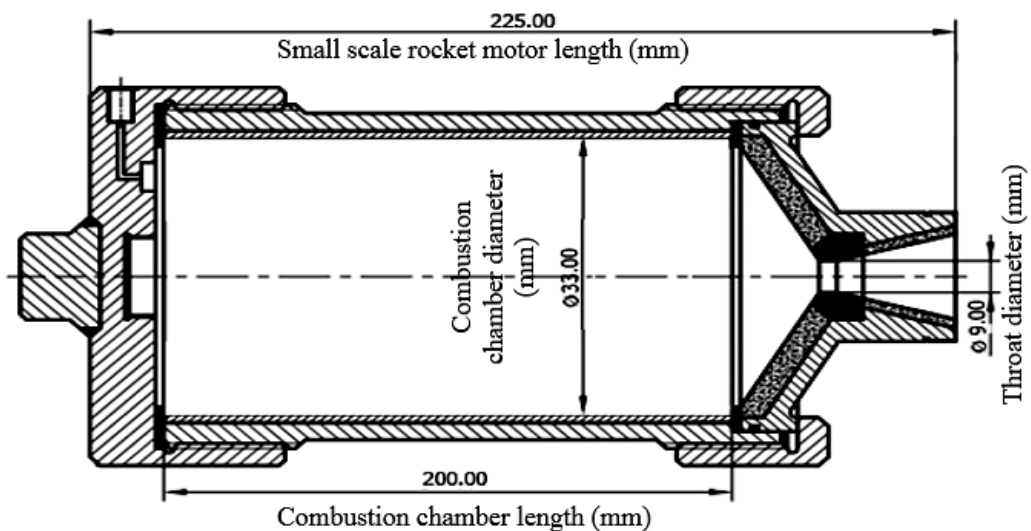


Fig. 5: Schematic for small scale test motor

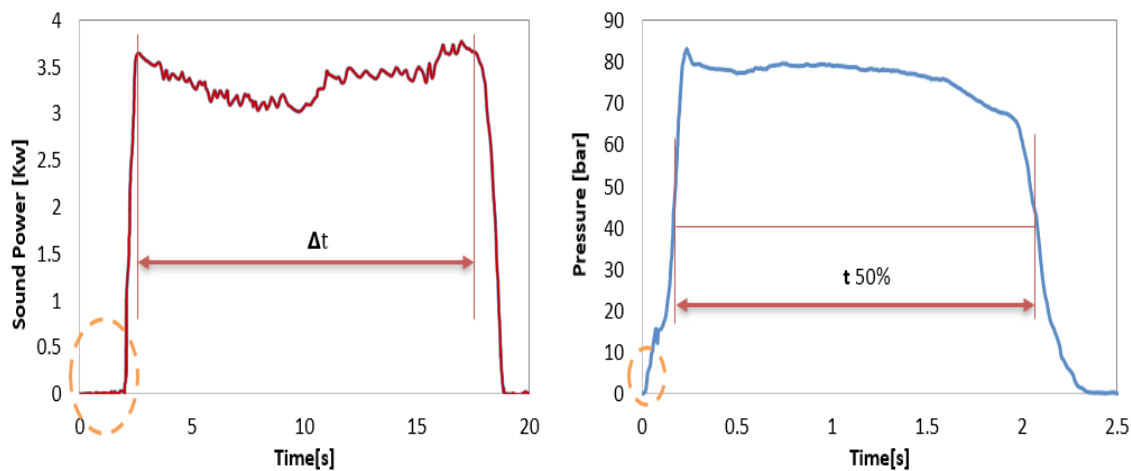


Fig. 6: Sound power-time and pressure-time curves.

III. RESULTS AND DISCUSSION

The combustion parameters could be calculated in accordance with burning rates measured under different pressures for both strand burner and 2-inch test motors as shown in Table. 2 by applying the burning rate eq. represented by Eq 2.

$$r = aP^n \quad (2)$$

Here: r is rate of burning (mm/s), a is constant of burning rate, n is the pressure exponent and P is the operating pressure (MPa).

Table 2: Comparative data obtained from strand burner and ballistic test motor.

	WAE strand burner					2-inch ballistic test motor					Crawford strand burner ^[13]				
	p	R	a	n	R2	P50%	R50%	a	n	R2	p	R	a	n	R2
	MPa	mm/s				MPa	mm/s				MPa	mm/s			
1	5	6.57				6.70	7.28				2	6.5			
2	6	6.89				7.92	7.60	2.7	0.23	0.99	4	6.89			
3	7	7.18	2.69	0.22	0.98	8.54	7.70				6	7.5	1.17	0.37	0.99
4	8	7.38									8	8.4			
5	9	7.50													

The burning rate of Crawford Strand burner was obtained by measuring the burning distance between the two lead wires as well as the burning time of such distance. Four values of burning rate were calculated^[13].

Values of P50% and R50% are chosen as expressed data to avoid the instability of burning at pressure built up and tail off regions^[20-23].

Acoustic emission strand burner has higher delay of

ignition time as chemical igniter in case of 2-inch motor is more powerful than electrical one as shown in Fig .6. This is because the typical products of the chemical igniter are high pressure gaseous products which accelerate the time required for sustainable burning stage and also glowing particles which improve the heat transfer to the first propellant surface layer reducing delay of ignition time.

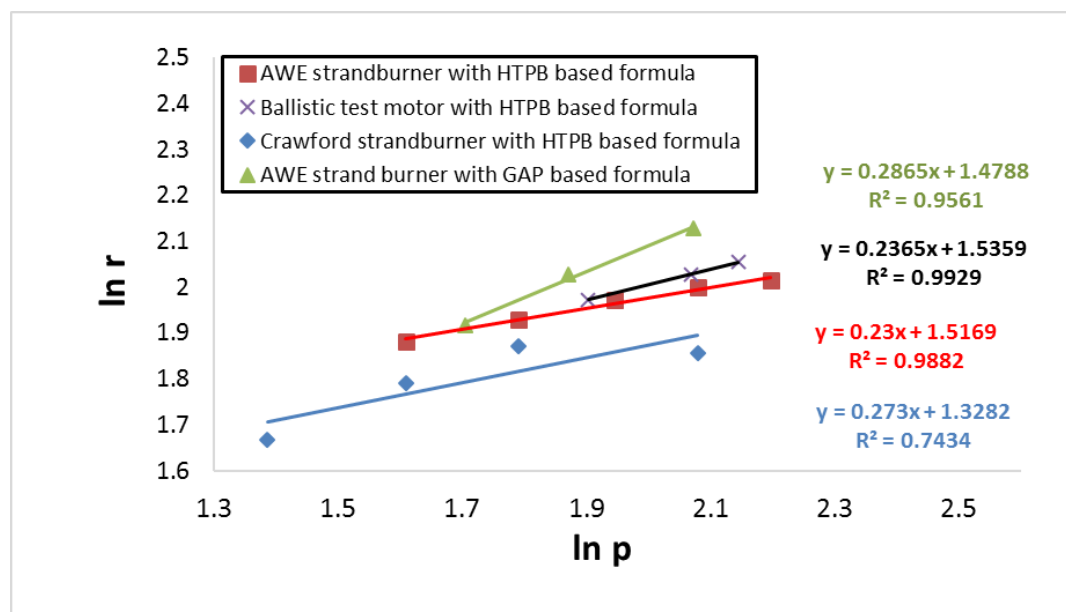


Fig. 7: comparative analysis of data obtained from both techniques.

Acoustic emission strand burner starts burning with sharp peak as it operates with already highly applied pressure unlike 2-inch motor burning which needs to operate exceeding built-up pressure value.

In case of acoustic emission strand burner after 10 sec, the curve gradually rises up which means increasing of

burning rate as a result of pressure accumulation (confined system) so it isn't recommended to increase the specimen dimension than previously mentioned. Burning of propellant could be extinguished by water so under water burning stability principle should be achieved by applying gaseous pulsation as shown in Figure 4(a), which means



that combustion layer is always protected from water by continuously generated gaseous bubble to overcome water tendency to fall down as a result of action of the gravity^[24,25].

In acoustic emission strand burner technique, water plays dual functions it used to inhibit the propellant specimen by dissolving AP presented on the outer surface creating low burning rate thin layer of inert binder matrix and also it used to enhance transferring of acoustic wave from burning surface to the acoustic wave sensor^[26,27].

The value of 3 % as strand burner deviation co-efficient has been evaluated by calculation of burning rates with strand burner and 2-inch motor at 6.894 MPa(1000 PSI) which founded to be 7.08 and 7.31 mm/s respectively. The acoustic wave emission strand burner for formulation based on GAP^[23] demonstrates high burning rate and high sensitivity to pressure by comparing with formulation based on HTPB. This could be investigated to the fact that GAP is more powerful energetic binder in comparison to HTPB^[28-30]. This also ascertain the validity of acoustic wave emission technique for different composite formulations with several operating parameters and wide range of applications^[22].

IV. CONCLUSION

The acoustic emission strand burner technique has many advantages over the conventional strand burners, unlike Crawford technique, acoustic emission technique requires no inhibitor no complex wiring and unlike small-scale test motor the acoustic emission technique requires small specimen to provide expressed ballistic data.

3% as acoustic emission technique deviation co-efficient was successfully investigated by comparing the burning rate of this technique and small-scale test motor at standard operating pressure 6.894 MPa(1000 PSI). Small deviation in pressure exponent has dramatic effect on burning rate of propellant. The higher burning rate of 2-inch motor was investigated as a result of the erosive burning.

The acoustic emission strand burner could be useful for safe estimation of burning rate of aged propellant of large-scale rocket motor with taking into account the estimated accuracy of this technique with the applied formulation.

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