Letter

Influence of venting parameters on erosive burning of partially cut multi-perforated stick propellants

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Abstract

Proper venting along the length was applied to mitigate the erosive burning effect of multi-perforated stick propellants. The relationship between the venting parameters and erosive burning was studied by interrupted burning experimental analysis. The stick-propellants grains recovered from interrupted burning test rig and the perforation radius at different positions along the length of stick-propellants were determined to characterize the extent of erosive burning. As the ratio of length to perforation radius of stick propellants increased from 261 to 523, there was a great fluctuation of internal radius indicating a more complex crossflow along the length of stick propellants. As minimum interval between cutting slots increased, the depth of coning shape also increased, indicating a more severe erosive burning. But the minimum intervals between cutting slots at the reverse side had little effect on the erosive burning. Larger width of cutting slot benefited the gases venting from it, indicating the erosive burning effect was mitigated.

Keywords : stick propellant, partially cut, erosive burning, ratio of length to perforation radius

1. Introduction

Numerous studies have noted that stick propellant has a number of very desirable ballistic advantages, resulting in an increase in gun performance and flexibility of charge design[1)−5)]. The natural flow channels associated with bundles of sticks reduce the resistance offered to the igniter and initial propellant combustion gases in comparison to a granular propellant bed, thus enabling a faster and more reproducible flame-spreading rate over the charge. This also reduces undesirable locally high pressure gradients and potentially severe longitudinal pressure waves in gun system. In addition, the regular packing of propellant sticks yields higher loading densities than for randomly packed granular propellant. Therefore, an equivalent performance could be achieved with a slightly increased mass of a lower-energy, lower-flame-temperature stick propellant[6)].

Multi-perforated stick propellants were not traditionally used because of overpressuration in the perforations that led to grain fracture and potentially serious performance problems, so classical stick charges employed single-perforation, longitudinally slotted stick propellant, to allow venting of perforation combustion products through the slot[7)]. To further enhance the capability of current stick propellant charge system, a more progressive and more densely-packed propellant configuration, i.e. the partially cut, multi-perforated stick configuration was developed by ARL to replace the slotted stick propellant[8)]. This high-progressivity/high-density (HPD) geometry employs multi-perforated sticks with partial transverse cuts at appropriate distances along their lengths such that (1) the ignition gases benefit from the favorable stick geometry while (2) subsequent gas production leads to separation at the transverse cuts and the required venting of perforations to assure acceptable and reproducible combustion behavior. As the interior ballistic cycle proceeds, the segments separate, tumble, and behave like conventional granular propellant.

There were many investigations on the cutting devices, combustion performance and firing tests of partially cut multi-perforated stick propellants[8)−10)]. Results showed that improved ballistic performance was obtained by using a multi-perforated partially cut stick propellants in place of the granular and single perforated stick propellant in gun system. It might be possible to achieve a six percent increase in velocity as predicted from ballistic calculations.

However, present works focused on combustion performance of partially cut multi-perforated stick propellants by using the closed vessel[11),12)] and gun firing[9),13)]. There exists the erosive burning in the combustion of stick propellant, which was studied extensively under different crossflow situation[14)-20)]. In order to obtain the high-progressivity/high-density performance, venting needs to be done differently[8)]. The proper venting can be an ongoing concern during the ignition and flame spreading process of multi-perforated stick propellants. The relationship between maximum chamber pressure and the proper venting of partially cut multi-perforated stick propellants were studied by Ruth et al.[8)]. However, the influence of venting parameters on erosive burning of stick propellants was seldom reported. Here, the relationship between the venting parameters and erosive burning is going to be studied by interrupted burning experimental analysis. The stick-propellants grains recovered from interrupted burning test rig and the perforation radius at different positions along the length of stick-propellants were determined to characterize the extent of erosive burning. It is helpful that the proper design of venting parameters can mitigate the severe erosive burning and the internal overpressurization of stick-propellants.

2. Experimental

2.1 Propellants

Samples for interrupted-burning test are 19-perforated stick double-base propellants plasticized with triethyleneglycol dinitrate (TEGDN). The venting parameters of 19-perforated stick propellants, such as ratio of length to perforation radius, minimum intervals between cutting slots at the same side of stick propellants, minimum intervals between cutting slots at the reverse side and width of cutting slot, are shown as Figure 1. Table 1 lists some parameters of 19-perforated stick propellants used in tests. Two kinds of web thicknesses of 19-perforated stick propellant were used in the experiments. "7/19" denotes that the burning web thickness is 0.7 mm theoretically (the measured value is 0.84 mm), and "12/19" denotes that the burning web thickness is 1.2 mm theoretically (the measured value is 1.44 mm).

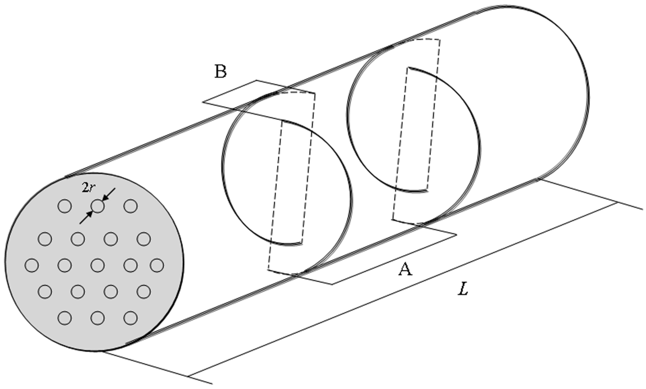

Figure 1 Schematic of venting method of 19-perforated stick propellants.
A-Minimum intervals between cutting slots at the same side
B-Minimum intervals between cutting slots at the reverse side
r-Internal radius of perforations
L-Length of 19-perforated stick propellants

2.2 Methods and setup

The interrupted-burning experimental setup consists of an igniter, a semi-closed combustion chamber and a special stopper composed of two bolts with a central shear hole in them. A metal burst disk is placed in the shear hole between the two bolts. The metal burst disk should be selected to ensure the termination of the burning propellant grains at the required pressure level. Figure 2 illustrates the interrupted-burning experimental setup. The conventional electric igniter consists of 1.1 g deterred nitrocellulose propellant powder and a fuse powered by power supply. The loading density of 19-perforated TEGDN stick propellants in the combustion chamber is 0.14 g/cm^3. A pressure gauge is attached on the side of the chamber. The blow-out pressure of interrupted burning experimental set-up is controlled by the thickness of burst disk. At a certain pressure, the burst disk ruptured. Rapid extinguishment of propellants occurred due to sudden depressurization. Then the unburnt propellant grains could be recovered for further tests. The maximum

Table 1 19-perforated TEGDN stick propellants used in tests.

Test label	Stick propellants	Web thickness [mm]	Length [mm]	Perforation radius [mm]	A [mm]	B [mm]	Width of cutting slot [mm]
1#	7/19	0.84	40	0.153	–	–	–
2#	7/19	0.84	80	0.153	–	–	–
3#	7/19	0.84	80	0.153	8	3	0.1
4#	7/19	0.84	80	0.153	16	3	0.1
5#	7/19	0.84	80	0.153	20	3	0.1
6#	7/19	0.84	80	0.153	40	3	0.1
7#	7/19	0.84	80	0.153	20	7	0.1
8#	12/19	1.44	80	0.318	20	3	0.1
9#	12/19	1.44	80	0.318	20	3	1

Notes : A-Minimum intervals between cutting slots at the same side ; B- Minimum intervals between cutting slots at the reverse side.

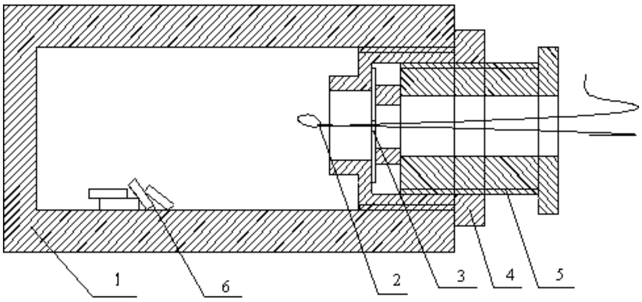

Figure 2 Schematic of interrupted burning experimental setup: 1-main body, 2-igniter, 3-burst disk, 4, 5-stopper composed of two bolts, 6-propellant.

pressure is referred as rupture peak pressure. It should be mentioned that the ruptured peak pressure is not always the same value because the burst disc is not uniform in material microstructure. The thickness of shear disc in the experiments is 1.2 mm. Accordingly, the blow-out pressure is about 30±5 MPa, as recorded by the pressure transducer.

The influence of venting parameters on the erosive burning is investigated in this study. Erosive burning effect of stick propellants can be observed using the variation of perforation radius along the length of stick propellants. The internal perforation diameter of recovered stick propellants at different positions along the length of stick propellants was measured through a microscope.

3. Results and discussion

3.1 Influence of ratio of length to perforation radius on variation of internal radius

It is well known the ratio of length to the perforation radius has significant effect on the erosive burning of single tubular propellant. Figure 3 shows the variation of internal radius of stick propellants with two kinds of ratios of length to perforation radius.

As seen in Figure 3, combined with the observation of recovered stick propellants, there exists coning phenomena at both ends of the internal surface of stick propellant perforations. This suggests a significant erosive burning in the combustion of stick propellant like rocket propellants. From Figure 3, The depth of coning shape is 0.129 mm for sample 1#. While it is 0.254 mm for sample 2#. In addition, as the ratio of length to perforation radius increases from 261 to 523, there is a great fluctuation of internal radius, indicating a more complex crossflow along the length of stick propellants. Therefore, in order to mitigate the erosive burning effect, the perforation of the stick propellant must be vented in proper manner so that propellant gases burning inside the perforation can escape to the out side of the grains.

3.2 Influence of minimum intervals between cutting slots at same side on the variation of internal radius

Figure 4 shows the variation of internal radius of recovered stick propellant at different minimum intervals between cutting slots at the same side along the length of

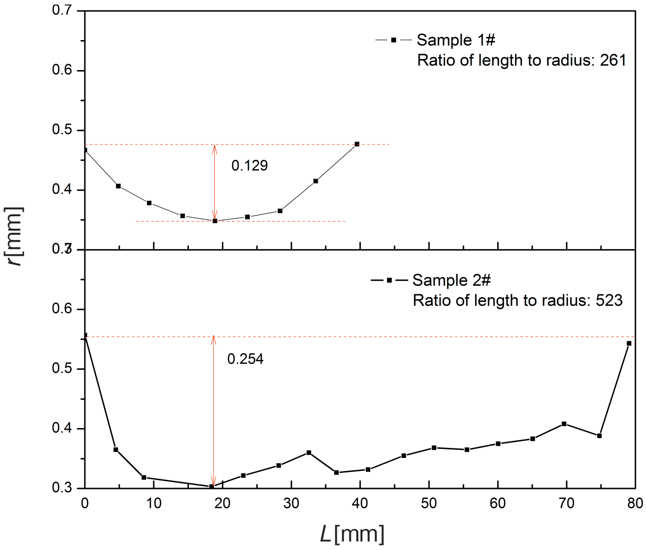

Figure 3 Variation of internal radius along the length of stick propellant with two kinds of ratios of length to perforation radius: (a) Sample1#, the ratio of length to perforation radius is 261; (b) Sample2#, the ratio of length to perforation radius is 523.

grain.

Stick propellants are vented at different minimum intervals along the length. The minimum intervals between cutting slots at the same side of four samples 3#, 4#, 5#, 6# shown in Table 1 are 8 mm, 16 mm, 20 mm, and 40 mm, respectively. As seen in Figure 4, with the increase of minimum interval between cutting slots at the same side, the depth of coning shape increases gradually, indicating a more severe erosive burning and pressure built-up, resulting from the crossflow which can increase the local gas velocity and burning rate.

3.3 Influence of minimum intervals between cutting slots at reverse side on variation of internal radius

At a constant width of cutting slot and minimum intervals between cutting slots at the same side, the minimum intervals between cutting slots at the reverse side of stick propellant sample 5# is 3 mm, while the minimum intervals between cutting slots at the reverse side of stick propellant sample 7# is 7 mm. Figure 5 shows the variation of internal radius of recovered stick propellant with different minimum intervals between cutting slots at the reverse side along the length. The depth of coning shape of two kinds of sample is close together, indicating the erosive burning is almost the same. The minimum intervals between cutting slots at the reverse side has little effect on the erosive burning.

3.4 Influence of width of cutting slot on variation of internal radius

Figure 6 shows the influence of width of cutting slot on the variation of internal radius of recovered stick propellant along the length. As seen in Figure 6, as the width of cutting slot increases from 0.1 mm to 1 mm, the depth of coning shape decreases from 0.203 mm to 0.185 mm, indicating the erosive burning effect is mitigated.

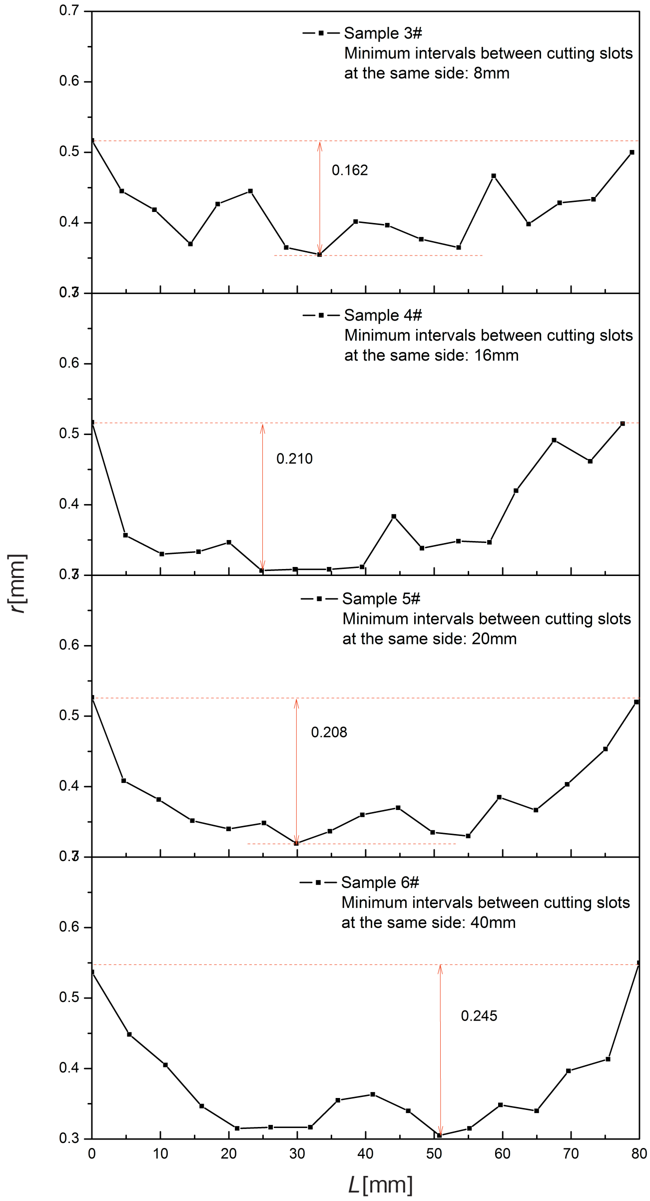

Figure 4 Variation of internal radius of recovered stick propellant along the length with different intervals between cutting slots at the same side.

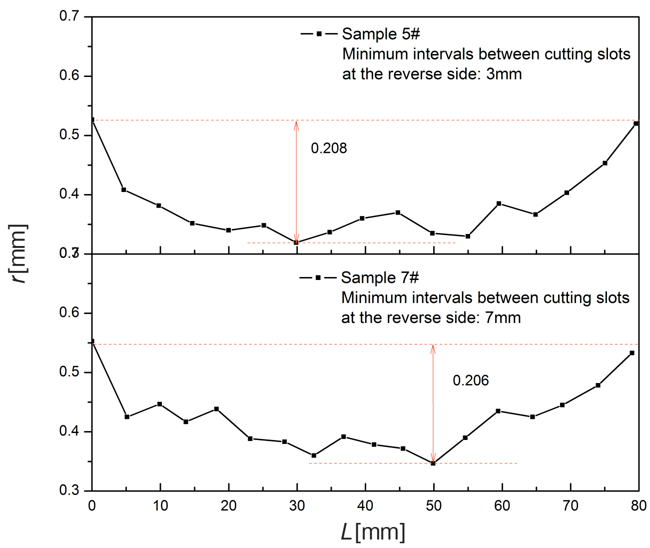

Figure 5 Variation of internal radius of recovered stick propellant along the length at different minimum intervals between cutting slots at the reverse side.

Larger width of cutting slot benefits the gases venting from it.

4. Conclusions

Erosive burning effect of stick propellant can be observed using the distribution of perforation radius along the length of stick propellant. There exist coning phenomena at both ends of the internal surface of multiperforation stick propellants, indicating erosive burning effect during the combustion of stick propellant. The depth of coning shape of varied with the venting parameters, such as the ratio length to perforation radius, minimum intervals between cutting slots at the same side of stick propellants, minimum intervals between cutting slots at the reverse side and width of cutting slot.

The influence of venting parameters on the erosive burning is investigated in this study. As minimum interval between cutting slots increases, the depth of coning shape increases, indicating a more severe erosive burning. But the minimum intervals between cutting slots at the reverse side has little effect on the erosive burning. Larger width of cutting slot benefits the gases venting from it, indicating the erosive burning effect is mitigated.

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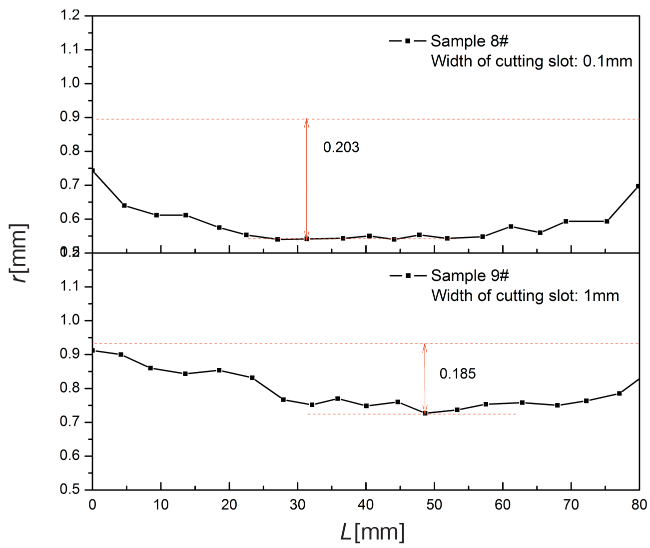

Figure 6 Variation of internal radius of recovered stick propellant along the length : at different widths of cutting slot.

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