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AN OPTICAL BOMB STUDY OF THE COMBUSTION OF SOLID PROPELLANTS IN HIGH ACCELERATION FIELDS

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INTRODUCTION AND SUMMARY

Under the subject program, an experimental study of the effects of acceleration fields on the burning rate of solid propellant grains is being conducted. The general plan is to investigate a variety of formulations over a range of pressures and acceleration loadings, the results to be used to evaluate theoretical models of the process or to form the basis for improved models. In this report the results for two formulations are presented. The acceleration vector in these tests, produced by spinning a disc-shaped grain, was directed normal to and away from the surface. For one of the propellants, which contained only CTPB binder and AP, the burning rate decreased approximately 20 percent at g-loadings of 500. At higher acceleration levels up to 1600 g's an additional 10 percent decrease appeared to occur, although the changes were too small to be determined with certainty. For a second propellant, similar to the first but containing 12 percent powdered aluminum, the change in burning rate if it existed at all was too small for any consistent trend to be detected at g-levels up to 2000. For both propellants the effects were independent of pressure up to 50 atm.

PROGRESS DURING PERIOD

Apparatus

During the present report period the experimental equipment, described previously (1), had to be disassembled and relocated within the facility. Advantage was taken of this opportunity to make some improvements and modifications to the apparatus. Presented below is a brief review of the equipment and its operation and the capability of the technique.

The basic apparatus consists of a large strand burner of approximately 1/2 cubic foot internal volume and rated for 2000 psi pressure. The burner contains the usual gas and electrical connections and also three windows, one of which provides for high-speed, high-magnification motion pictures of the burning process. Samples of propellants are cast in the shape of a disc 1-1/2 inches in diameter by 1/4-inch thick, and are mounted on the shaft of a DC motor. Mountings for two configurations are provided depending upon whether the propellant is to be ignited on the periphery to measure the effect of acceleration away from the surface, or ignited on an inner annular surface to measure the effect of acceleration into the surface. No experiments have yet been performed on the latter configuration although the major effort of the program will be with this type.

The discs are spun at carefully controlled speeds prior to ignition, and spin rates of 10,000 rpm are readily attained corresponding to initial g-loadings of >2000 for peripherially ignited samples. The camera views one face of the disc and this side is inhibited by leaching the surface with water and applying a thin coat of Silicone grease. The face away from the camera is inhibited with epoxy. Ignition on the periphery of the spinning disc is accomplished with a small piece of another propellant mounted next to it and ignited in turn by a hot wire. Ignition on the inner annular surface will be by the same method. A 16 mm Fastax camera is used for photographing each experiment. Framing rates of up to 2000 frames/second have been used and magnifications of approximately 2:1 image-to-object have been achieved using long lens extension tubes. At these high magnifications, resolution of approximately 10 microns is attained, however, depth of focus must be sacrificed. Although the original quality is lost in reproduction, some idea of such motions pictures will be obtained from Figure 1, which shows four individual frames, when it is analyzed below. Runs in which only surface regression rates are desired are filmed at much less magnification. The burning rates are determined from the decrease with time in diameter of the propellant disc. Spin rates are determined from the motion pictures and checked against a calibration of motor speed versus input power.

Quite a number of runs have been made prior to the data-collecting experiments, to identify and solve expected problems. In general the apparatus s now working satisfactorily although some operational improvements would be desirable. The main problem remaining is that of excessive smoke during propellant burning, which obscures the camera view of the event in some instances.

Results

To date two propellant formulations have been investigated. The first was a CTPB binder propellant containing only fuel and AP in the weight ratio 18:82. Bimodal AP of 20 and 200μ particle size was used in the ratio of 1:3. The second propellant was the same as the first except 12 percent of powdered aluminum of 20μ particle size was added. The fuel to AP ratio was 15:73 which is approximately the same as the first, and the same ratio of bimodal AP was used. These two formulations will be designated CTPB-VO and CTPB-Al-VO, respectively. The burning rate equations, $r_o = bP^n$, were measured to be: $r_o = 0.164\ P^{0.419}$ for CTPB-VO

$r_o = 0.147\ P^{0.424}$ for CTPB-Al-VO

where P is in atm and r_o is in cm/sec. Both formulations had about the same deflagration rate, the nonaluminized being slightly greater.

Both of these propellants were studied at three pressures of 10, 30 and 50 atm, and at each pressure two acceleration levels of nominal 600 and 1500 g's were tested. The acceleration vector was normal to and away from the surface. The results are collected in Tables I and II and the following explanations of how the data were derived apply. The radius of the disc was measured at intervals as the propellant burned. The individual measurements of burning rate listed in the tables under <u>r</u> correspond to such intervals, and the corresponding g's are also listed. The g-value decreases as the propellant ablates; it is computed from the formula

$$g = R \times rpm \times 1.126 \times 10^{-5}$$

which is readily derived from elementary physics principles, where R is the propellant disc radius in cm and rpm is the spin rate in revolutions per minute. The individual values of <u>r</u> as the radius decreases show a nigh degree of scatter and exhibit no general trend. These are only measured every 2-3 mm

Table I. Results of Effect of Outward-Directed Acceleration Fields on Burning Rate for Propellant CTPB-VO

Run	P (atm)	rpm	R (cm)	g	r(cm/sec)	r/r_0	average r	avg. g	avg. r/r_0
18	10	6000	1.60	650	.37	.88	.34	535	.80
			1.24	505	.34	.80	±.02		
			1.10	445	.31	.73			
22	10	8750	1.84	1580	.26	.61	.30	1350	.71
			1.71	1470	.28	.66	±.02		
			1.57	1350	.34	.80			
			1.42	1220	.31	.73			
			1.29	1110	.30	.71			
17	24	5760	1.81	677	.40	.66	.49	550	.80
			1.59	595	.56	.92	±.06		
			1.34	502	.54	.89			
			1.12	420	.46	.75			
21	24	8750	1.82	1560	.46	.75	.53	1290	.87
			1.69	1450	.37	.61	±.10		
			1.52	1310	.77	1.26			
			1.32	1130	.52	.85			
			1.16	1000	.52	.85			
19	50	5850	1.76	680	.65	.78	.67	585	.81
			1.51	585	.65	.78	±.02		
			1.26	490	.70	.84			
20	50	8750	1.84	1600	.52	.63	.54	1550	.65
			1.73	1500	.56	.67	±.02		

P	r_0
10	.425
24	.610
50	.830

Table II. Results of Effect of Outward-Directed Acceleration Fields on Burning Rate for Propellant CTPB-Al-VO

Run	P (atm)	rpm	R (cm)	g	r(cm/sec)	r/r_o	average r	avg. g	avg. r/r_o
9	10	6000	1.81	734	.32	.82	.35	630	.90
			1.61	651	.41	1.05	±.03		
			1.44	584	.33	.85			
			1.28	519	.33	.85			
11	10	9800	1.74	1880	.32	.82	.36	1670	.92
			1.71	1850	.37	.95	±.03		
			1.57	1700	.35	.90			
			1.42	1540	.43	1.10			
			1.27	1370	.32	.82			
12	30	6750	1.69	865	.66	1.06	.64	763	1.02
			1.35	690	.66	1.06	±.02		
			1.14	585	.61	.98			
13	30	9800	1.80	1940	.65	1.04	.61	1760	.98
			1.64	1660	.50	.80	±.06		
			1.46	1580	.69	1.10			
			1.28	1380	.61	.98			
14	50	6420	1.80	835	.65	.83	.85	715	1.08
			1.52	705	.98	1.25	±.13		
			1.25	580	.92	1.17			
15	50	9800	1.86	2000	1.01	1.29	.69	1940	.88
			1.80	1940	.54	.69	±.19		
			1.73	1870	.60	.76			

P	r_o
10	.390
30	.625
50	.785

and this may be one of the major reasons for the scatter. The average values of r̲, however, represent measurements over approximately 1 cm of surface regression and these do exhibit certain significant trends. In the last column of the tables are shown the ratios of average burning rate under acceleration loads to burning rate without acceleration. The burning rate reduction ratios are the counterpart of the augmentation ratios which are usually used in discussing burning rate increase with acceleration when the direction is into the surface.

An analysis of the results of Table I and II will be made which concentrates on the main features of the study. First, one can immediately see that the burning rate reduction is quite small in all cases, even at acceleration levels approaching 2000 g's. If the acceleration vector were into the surface, it would be expected that the burning rate augmentation would be ∿100-200% for propellants of these normal burning rates based on the work of others (2). There is no logical reason to assume that for the vector-out accelerations of these experiments a 100-200% reduction in burning rate should therefore be found. However, the small observed reductions of approximately a factor of ten less are quite surprising. In fact, for the aluminized propellant the data show no change in burning rate with acceleration within the limits of the precision which are roughly 5-10%. Also, for this propellant, the burning rate invariance holds up to at least 50 atm pressure.

For the nonaluminized formulation, accelerations out from the surface of ∿500 g's cause burning rate decreases of approximately 20%. Further reduction of 10-15% at higher g-values of 1300-1500, appears to occur although run #21 is anomalous in this respect. This was quite an erratic test, however, as can be seen from the individual burning rate values and will be repeated. Finally, up to 50 atm pressure there is no change in the degree of reduction of burning rate. The data are not plotted on graphs as the trends and interpretation can be seen quite well from the tables.

We turn now to a description of the high-speed, high-magnification motion picture capability. Four frames from a film roll are shown in Figure 1.

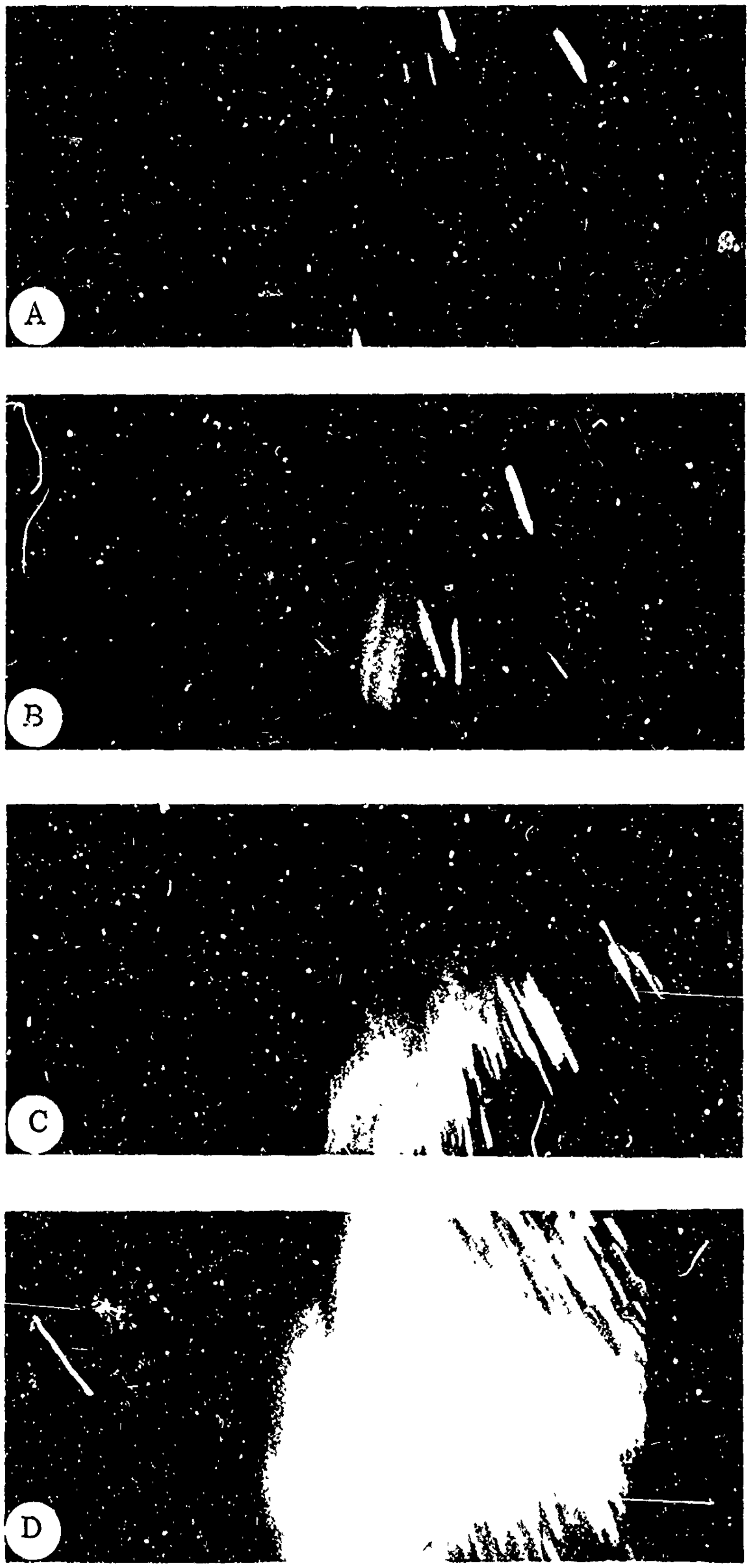

Figure 1. Selected Frames from High-Magnification Motion Picture of an Aluminized Propellant Burning under a 390 g Acceleration Force Normal to and Away from the Surface.

These are of the aluminized propellant burning at 24 atm under a g-load of 390. Frames (a) and (b) are successive frames early in the burn when uniform ignition over the entire periphery had not yet been attained. Frames (c) and (d) are later in the run and are not successive. The propellant edge which cannot be very well discerned in the figure, runs approximately down the center of each frame. The disc is spinning clockwise and the streaks are, of course, burning aluminum particles; the scale is roughly 15:1. The angular velocity of the propellant disc at the periphery is ~900 cm/second; the velocity of the particles 1-2 mm away from the surface has been measured to be ~500 cm/second. The original particle size of the aluminum powder was 20μ in diameter. The streak widths on the figure range from approximately 20 to 120μ. The streaks of narrower width are the fainter ones and these may appear narrow because they are beyond the focal plane which is much less than the 1/4-inch thickness of the disc. In any case the evidence indicates little or no agglomeration of metal particles. When high-magnification pictures are taken of the more interesting case of burning under an inward directed acceleration field, the particle streaks may reveal significant information on the extent of agglomeration, or more correctly, what size the particles are that can escape from the surface.

One final comment should be made on the method and this concerns the possible complication of errosive burning. Errosive burning apparently becomes of concern at axial gas velocities of the order of hundreds of feet per second in rocket motors. At the highest spin rates encountered, 9800 rpm, and the maximum disc diameter, 3.80 cm, the propellant velocity relative to the "stagnant" pressurizing gas is calculated to be 64 ft/second which is well below the above threshold. Therefore, assuming that errosive burning would set in at approximately the same gas velocities for spinning discs as for, say, centrally perforated grains, it should not be significant in the present study.

PLANS FOR FUTURE WORK

Of the two possible directions of applying an acceleration field, into and away from the surface, the latter seems to be the less interesting.

This is true from a practical point of view, but also the results to date indicate that there is only a small effect and sometimes none at all when the spin vector is away. Consequently it is planned to devote most of the future effort to the other case. Before this is started, however, one other formulation will be investigated in which a solid catalyst is incorporated into the propellant. As the solid particles emerge from the propellant they will be pulled from the surface by the centrifugal force. Depending upon how the rate is affected it may be possible to determine by what mode catalysts such as copper chromite or iron oxide act to enhance burning. For example, if they catalyze reactions below the propellant surface in the preheat region of the combustion wave, presumably no effect should be found. On the other hand, if they act on or above the surface, a drastic decrease in burning velocity should result.

REFERENCES

1. Atlantic Research Corporation,"An Optical Bomb Study of the Combustion of Solid Propellants in High Acceleration Fields," First Annual Progress Report, Contract N0014-67-C-0455, May 1968.

2. Anderson, J.B. and Reichenback, R.E., "An Investigation of the Effect of Acceleration on the Burning Rate of Composite Propellants," AIAA Journal 6, 271(1968).

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13 ABSTRACT

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