Low-Pressure Combustion of Solid Propellants

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IN previous work[1] a correlation of the critical pressure and chamber characteristic length L^* was developed. This correlation gives the theoretical limits of critical pressure where low-frequency combustion instability and ultimate extinction can occur. Experimental studies[2] conducted with polyurethane-type composite propellants indicated that the extinction pressure, although independent of the burning geometry, was strongly dependent upon motor L^* and certain other parameters, such as the aluminum concentration in the propellant. For nonaluminized propellants, the slope of L^* vs extinction pressure (P_e) was $-2n$‡ as predicted theoretically; however, the slope became steeper with the addition and increased concentration of aluminum in the propellant. In later studies,[3] when coarser aluminum was substituted in the propellant, the effect was to cause incomplete combustion at the low pressures, and the slope of the relationship and burning characteristics showed a trend approaching those of nonaluminized propellant. These results are shown in Figs. 1 and 2.

Additional studies have been conducted to determine the effect of oxidizer particle size on the L^* vs P_e relationship. Two propellant formulations were used, each having the same percentage aluminum (Al), ammonium perchlorate (AP), and binder in the propellant. One formulation had a unimodal AP distribution with an average particle size of approximately 400 μ (+48 mesh) and an average Al particle size of approximately 7 μ. The other formulation had a bimodal AP(70/30)

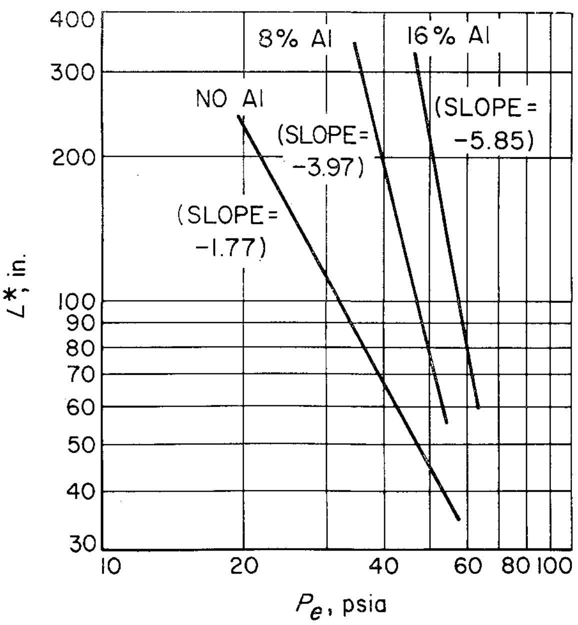

Fig. 1 Effect of Al concentration on L^* vs P_e relationship, 3-in.-diam test motor, $T_0 = 80°F$, Al particle size ≈ 7 μ, AP(70/30) bimodal distribution, unground ≈ 170 μ, ground ≈ 17 μ.

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‡ n = pressure exponent.

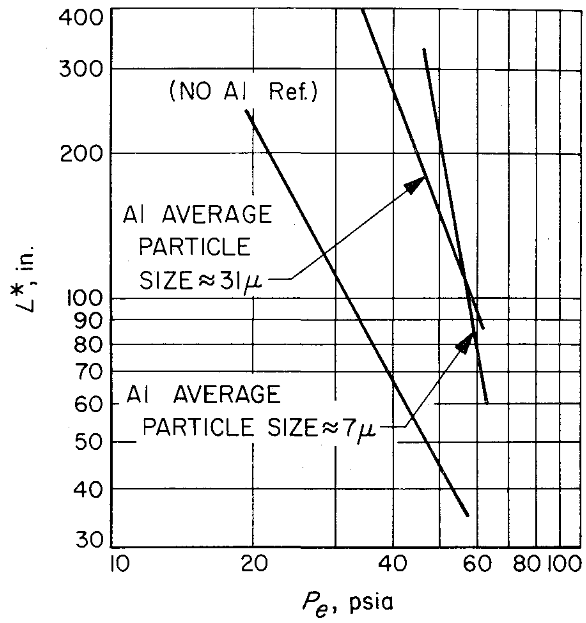

Fig. 2 Effect of Al particle size on L^* vs P_e relationship, 3-in.-diam test motor, $T_0 = 80°F$, 16% Al in propellant, AP(70/30) bimodal distribution, unground ≈ 170 μ, ground ≈ 17 μ.

distribution (unground 400 μ, ground 17μ) with an Al particle size of approximately 31 μ. Burning-rate data for these formulations in the low-pressure region were obtained by using the Crawford bomb strand burner. These data, along with Jet Propulsion Laboratory (JPL)-540 propellant used in the earlier studies, are shown in Fig. 3. The formulation with the fine Al particle size, but with the coarser unimodal AP particle size distribution, suppressed the burning rate as expected, because of reduced packing density. However, it was interesting to find that the other formulation with the coarser oxidizer particle size, but also with the coarser Al particle size, resulted in a higher burning rate than the JPL-540 propellant.

For low-pressure extinction tests, regressive burning $2\frac{1}{2}$ in.-diam and 4 and $4\frac{1}{2}$ in.-long cylindrical charges were used in the 3-in.-i.d. test motor. Using the standard squib-pellet igniter system, these modified propellants could not be ignited either under vacuum or atmospheric firing conditions. Ignition was not obtained under vacuum conditions even with a hotter

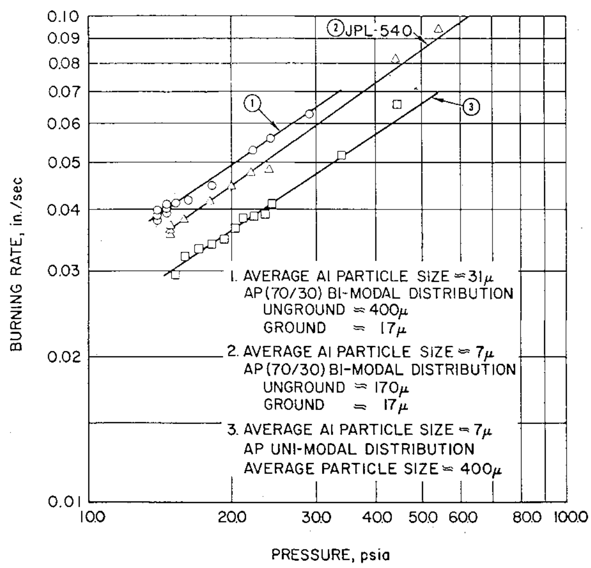

Fig. 3 Burning-rate-pressure relationship, 16% Al in propellant.

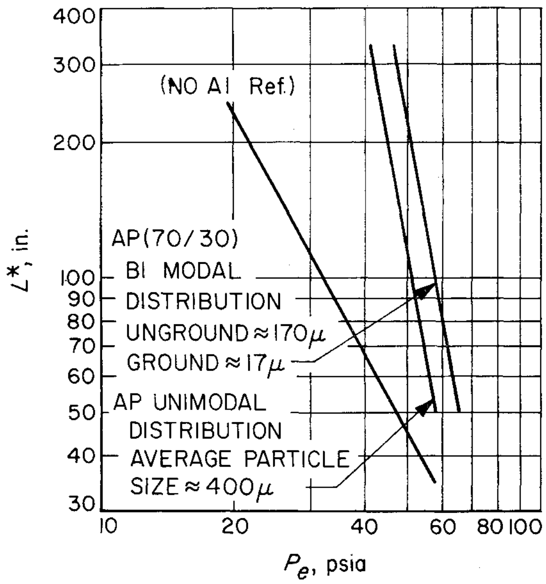

Fig. 4 Effect of AP particle size on L^* vs P_e relationship, 3-in.-diam motor, T_0 = 80°F, 16% Al in propellant, average Al particle size ≈ 7 μ.

igniter. Finally, satisfactory ignitions were obtained by attaching strips of a different easily ignitable propellant to these charges. The subject of sensitivity of ignition to pressure and the controlling factors for ignition with varying concentration and particle size of Al and AP in the propellant are currently under investigation. The results of the tests for the evaluation of coarser oxidizer particle size in propellant are shown in Figs. 4 and 5. The pertinent conclusion that can be drawn is that the slope of L^* vs extinction pressure relationship is not affected by the variation of oxidizer particle size in the propellant, and the variation in extinction pressure at a given L^* is small.

Some of the conclusions, which can be drawn from the various phases of the experimental program conducted at JPL can be summarized briefly as follows: 1) for a given propellant, the L^* vs extinction pressure relationship is a valid parameter for determining the low-pressure stable combustion limit; 2) for nonaluminized propellant, the slope of L^* vs P_e is

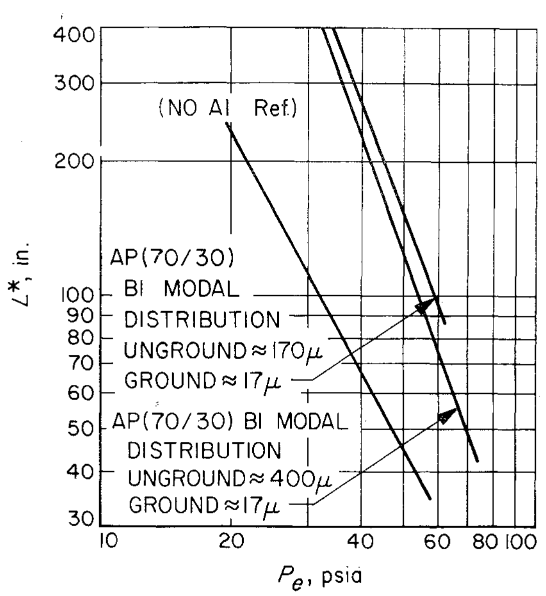

Fig. 5 Effect of AP particle size on L^* vs P_e relationship, 3-in.-diam motor, T_0 = 80°F, 16% Al in propellant, average Al particle size ≈ 31 μ.

$-2n$, as predicted theoretically for critical pressure; 3) the slope of L^* vs P_e relationship is affected by the presence of Al, the concentration of Al, and the Al particle size in propellant; 4) the effect of coarser Al in propellant is to cause incomplete combustion at low pressures, and the burning and extinction characteristics tend to approach those of nonaluminized propellant; and 5) the variation in oxidizer particle size has a negligible effect on the L^* vs P_e relationship; the small differences in extinction pressure at a given L^* are attributed to the variation in packing density.

References

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Use of Biot's Variational Technique in Heat Conduction

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RECENTLY several papers using Biot's method have appeared indicating an increased interest in the use of variational techniques in the determination of temperature profiles. Because, under some conditions, the variational techniques admit several solutions, it is well to comment on the technique.

When the temperatures are prescribed on the surfaces and polynomial representations are used for the temperature profile in the media (e.g., Refs. 1–3), one normally introduces into the polynomial certain free parameters (termed generalized coordinates) that are to be determined by the solution of Biot's differential equations. In general, for a given profile, there will be only one solution. If, however, the heat flux and not the surface temperature is prescribed, then an additional free parameter for the temperature of each surface must be included. Now all of these generalized coordinates may be determined through Biot's equations and Lardner's[3] energy content equation, or one may use the surface flux conditions and reduce the number of variational equations. These two methods produce differing results, and the choice

Table 1

$\dot{H}_x\|_0 = F$	$-k(\partial\theta/\partial x)\|_0 = F$
$H_x = Ft[1 - (x/q_2)]^3$	$H = \left(\dfrac{Fc}{6k}\right) q_2^2 \left[1 - \left(\dfrac{x}{q_2}\right)\right]^3$
$V = 9F^2t^2/10cq_2$	$V = cF^2q_2^3/40k^2$
$D = \dfrac{1}{2k}\left\{\dfrac{F^2q_2}{3} + \dfrac{3F^2t^2\dot{q}_2^2}{35q_2} + \dfrac{F^2t\dot{q}_2}{7q_2}\right\}$	$D = \dfrac{11}{24}\,\dfrac{F^2c^2q_2^3\dot{q}_2^2}{35k^3}$
$q_2 = 2.81\ (\alpha t)^{1/2}$	$q_2 = 2.65\ (\alpha t)^{1/2}$

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