Technical Notes

Plateau Ballistics in Nitrocellulose Propellants

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Introduction

BALLISTICS of double base systems containing inorganic and aliphatic lead compounds were described previously.[1] The plateaus (regions of low n in $r = cP^n$, burning rate r and pressure P) were generally below 0.4-in./sec burning rate and 2000-psi pressure. Extension of formulation work to aromatic salts has established higher burning rates. Pigmenting these propellants further increases burning rates, and this pigment effect has been confirmed in aliphatic plateau propellants as well.

Experimental Procedure

The propellants were prepared by solvent extrusion. Ballistics reported are strand burning rates in closed bomb equipment using a 5-in. burning distance. Results have been confirmed in rocket firings.

Aromatic Lead Salts

Early plateau investigations with inorganic and aliphatic lead compounds[1,2] gave way to aromatics because of known differences in solubility and in order to define limitations of the phenomenon. High-energy systems were devised, and aromatic plateaus[3] were obtained at 1500 cal/g or higher. Figure 1 shows a number of typical plateaus labeled as to calorific value, but not identified as to specific lead compound. For reference, two nonplateau lines are shown, one at 850 cal/g and one at 1440 cal/g. Plateau burning rates are uniformly higher than reference rates at a given pressure, especially at the low-pressure edge of the plateau. Table 1 shows

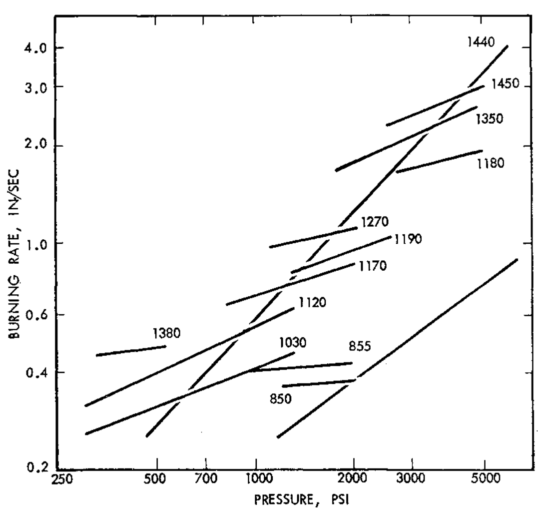

Fig. 1 Aromatic lead salt plateaus.

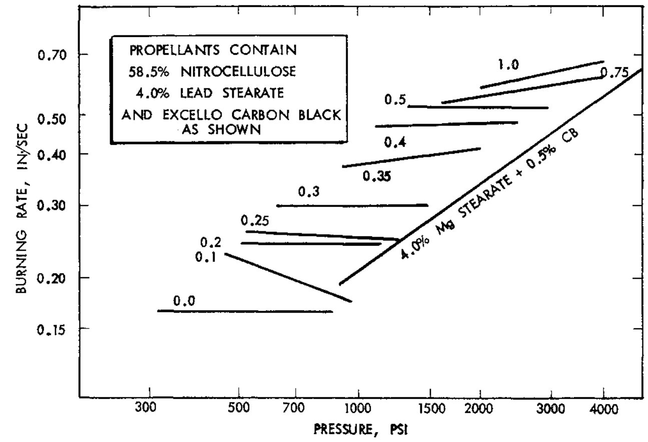

Fig. 2 Plateau ballistics of blackened propellants.

plateau propellant formulations along with temperature coefficients of equilibrium pressure π determined from temperature coefficients of burning rate.

Persistence of the plateau effect at very high energy may result from high thermal stability of aromatics (compared to aliphatics) in the crucial reaction zone. Pyrolyses of both aliphatic and aromatic lead salts have offered plateau-producing pyrolyzates.[4] Pyrolyses were performed at temperatures up to 750°C, considerably higher than measurements at the burning surface. Thus, pyrolyzate may furnish the important catalyst at or near the receding surface.

Pigmented Plateau Propellants

Experiments with carbon black showed increases in burning rate which prompted investigations of particle size, method of manufacture, etc. Other small particle refractory materials were tried and some effect found. Most effective, and the only practically useful materials, were the carbon blacks; their most important property seemed to be particle size (specific surface).

Carbon black, Excello (Imperial Gas and Oil Company) was used in early propellants[5] containing 4% lead stearate and 58.5% NC at 760–800 cal/g to give the data plotted in Fig. 2. Quite striking plateau rate increase occurs at low concentrations, but above 0.5% carbon, the plateau slopes rise and the relative rate increase falls off. Above 1% carbon black the plateau disappears, and burning rates fall because of the decrease in propellant energy. Smaller particle carbon blacks resulted in higher rates, suggesting a simple surface effect

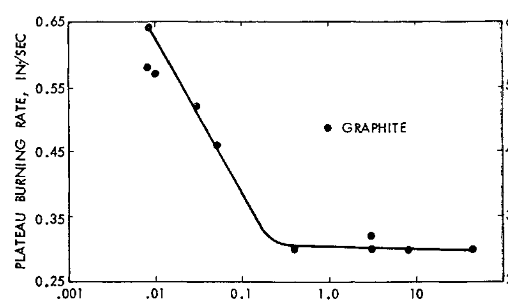

Fig. 3 Plateau burning rate vs pigment particle size.

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Table 1 Plateau propellants with aromatic lead compounds

NC[a]	NG[a]	TA[a]	NDPA[a]	Salt	H_{ex}, cal/g	π, %/°F
30	67	...	3	0	1440	1.0
30	67	...	1	2 (benzoate)	1450	0.57
35	60	...	1	4 (phthalate)	1380	0.60
45	52	...	1	2 (benzoate)	1350	0.55
50	47	...	1	2 (benzoate)	1270	0.60
50	43	3	1	3 (tannate)	1190	0.60
50	43	4	1	2 (benzoate)[b]	1180	0.60
50	43	4	1	2 (benzoate)	1170	0.70
58.5	37	...	2.5	4 (salicylate)	1120	0.37
59.5	33	4	2.5	2 (trimesate)	1030	0.41
58.5	27	10	2.5	2 (thiosalicylate)	855	0.06
58.5	27	10	2.5	2 (anthranilate)	850	0.14
58.5	27	12	2.5	0	850	0.80

[a] NC = nitrocellulose of 12.6% N, NG = nitroglycerine, TA = triacetin, and NDPA = 2-nitrodiphenylamine.
[b] Contains 0.2 carbon black (Carbolac I) on added basis.

Table 2 Burning rates in the plateau for a composition like that of Fig. 2, obtained at 0.5% carbon black

	Rate at 2000 psi and 25°C, in./sec
Excello 0.030 μ average particle diameter	0.52
Neo Spectra Mk I 0.010 μ (Binney & Smith Co.)	0.57
Kosmos F-4 0.008 μ (United Carbon Co., Inc.)	0.58
Carbolac I 0.009 μ (Godfrey L. Cabot, Inc.)	0.64

Table 3 Burning rates obtained with 0.5% pigment in the standard formulation

	Rate at 2000 psi and 25°C, in./sec
Excello 0.030 μ	0.52
Graphite 1.0 μ	0.48
Hydrated alumina 0.5 μ	0.48
Acetylene black 0.05 μ	0.46
Phthalocyanine	0.37
Titanium oxide 0.4 μ	0.31
Magnesium oxide	0.31
Levigated alumina 3 μ	0.31
None	0.31

(see Tables 2 and 3). Although the graphite has a nominal particle diameter 1 μ, its very thin leaflets afford far more surface than the denser TiO_2 at 0.4 μ with a more compact particle. At higher concentrations TiO_2 gives plateau rate boosts (to 0.44 in./sec at 1%).

A plot of plateau rate vs particle size is shown in Fig. 3. If actual specific surface data were available, the smoothness of fit of the points on the curve might be improved. At particle sizes much above 0.1 μ, little or no rate boost is observed and the pigment loses ballistic effect.

Combining high rate promoters, i.e., aromatic lead salts, high energy, and small particle carbon black has led to the highest plateau burning rates encountered in nitrocellulose systems.[6] An example containing 4% lead 2,4-dihydroxybenzoate and 0.4% carbolac I at an energy of 1350 cal/g showed a rate of 1.1 in./sec at 1100 psi with plateau ballistics. Omission of carbon black drops the rate to 0.8 in./sec at this pressure, and decrease of either lead salt or carbon black leads to more or less loss in burning rate. Substantial increase of concentration of either of these coolant ingredients results in decreased burning rates. One observes a maximum burning rate system, in a given range of salt and carbon black concentrations, which is very sensitive to mixing and requires good process control. Any local excess or deficiency of either or both of the minor constituents leads to burning rate decrease.

References

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Torsion of an Elastic Cylinder of Unsymmetrical Aerofoil Cross Section

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In this note the method developed by Deutsch[1] is applied for solving the Saint-Venant torsion problem of an elastic cylinder whose cross section resembles an unsymmetrical aerofoil. The method consists of mapping the cross section of the beam conformally on a unit semicircle and solving the resulting Dirichlet problem.

1. Basic Equations

Let

$$Z = w(\zeta) \tag{1.1}$$

be the function that maps conformally a region S of a Z plane ($Z = x + iy$) on the semicircle $|\zeta| \leqslant 1$, $\eta \geq 0$ of a ζ plane ($\zeta = \xi + i\eta$). Let $f(z)$ be the complex-torsion function[2] of the region S and let $\phi(\zeta) = \phi[w(\zeta)]$ be the same complex torsion function expressed in terms of the variable ζ.

Then the complex torsion function is given by[1]

$$\phi(\zeta) = \frac{1}{2\pi}\int_\gamma w(\sigma)\bar{w}\left(\frac{1}{\sigma}\right)\left(\frac{1}{\sigma-\zeta}+\frac{1}{\sigma-(1/\zeta)}\right)d\sigma + \frac{1}{2\pi}\int_{-1}^{+1} w(\xi)\bar{w}(\xi)\left(\frac{1}{\xi-\zeta}+\frac{1}{\xi-(1/\zeta)}\right)d\xi \tag{1.2}$$

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