Some Experiments on Model Composite Solid Propellants

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Untersuchungen über Composit-Festtreibstoff-Modelle

Es werden Versuche an zweidimensionalen Treibstoffmodellen beschrieben, bei denen ein Oxidator (Ammoniumperchlorat) mit zylindrischem Korn in der Brennstoffmatrix (CTPB) verwendet wurde. Die Messungen zeigen, daß die Abbrandgeschwindigkeit des Ammoniumperchlorats in der Brennstoffumgebung niedriger ist als bei reinem AP. Das Verhältnis Oxidator/Brennstoff scheint auf der Brennstoffseite zu liegen, wenn die Oxidatorpartikel in den Brennstoff eingebettet sind, und liegt auf der Oxidatorseite, wenn der Abstand zwischen Oxidatorteilchen und Brennstoff von null verschieden ist.

Etude de modèles de poudres propulsives composites

On décrit des essais effectués avec des modèles bidimensionnels de poudres propulsives, dans lesquelles le comburant (perchlorate d'ammonium), sous forme de grains cylindriques, est enrobé dans une matrice constituée par le combustible (CTPB). Les mesures montrent que la vitesse de combustion du perchlorate d'ammonium entouré de substance combustible est moins élevée que celle du perchlorate d'ammonium pur. Il semblerait que le mélange soit trop riche en combustible quand les particules de comburant sont enrobés de combustible et qu'il devienne trop riche en comburant, dès que les particules de comburant ne sont pas en contact direct avec le combustible.

Summary

Experiments on two-dimensional model propellants using cylindrical oxidizer (ammonium perchlorate) pellets in a fuel matrix (CTPB) are described. Measurements show that burning rate of AP in the fuel environment is lower than of pure AP. The oxidizer-to-fuel ratio seems to be fuel-rich when the oxidizer particles are imbedded in contact with the fuel and it becomes oxidizer-rich for a non-zero separation between oxidizer particle and the fuel.

Experiments on composite solid propellants using two-dimensional sandwich models have been made by several workers. These simplified models have been claimed to be useful for studying the interface details during combustion. These experiments and their primary conclusions have been summarized by Boggs[1] et al. Some of the primary conclusions of the more recent studies of Boggs and Zurn[1] and Varney and Strahle[2] are

- there is a flow of binder melt on the adjacent oxidizer surface, but no evidence of significant heterogeneous reaction,
- the gas phase structure during high pressure burning is likely to be turbulent and
- the average regression rates of polysulfide(PS)-ammonium perchlorate(AP) sandwiches and polybutadiene acrylic acid(PBAA)-AP sandwiches are higher than that of AP; the average regression rate of carboxy-terminated polybutadiene(CTPB)-AP and polyurethane(PU)-AP sandwiches are lower than that of AP over a range of pressures upto 150 atm.

After examining these earlier studies it was thought worthwhile to attempt the study of two-dimensional sandwiches using cylindrical pellets of AP embedded in a fuel binder. Such a model would be closer to the situation obtaining in an actual propellant and possesses, in addition, a flexibility for configurational changes.

The present study is largely confined to CTPB-AP system. Cylindrical pellets of as-is-received AP of 6 mm diameter and of lengths varying from 12 mm–24 mm were obtained by pressing the powder in a die-using hydraulic press. The density of the cylindrical pellets was measured as about 1.91 g/cm^3. The model propellants were expected to be placed in a manner the oxidizer particle finds itself in a fuel environment similar to what happens in a propellant except that the two-dimensional analog is used here. The various configurations tested are shown in Fig. 1. The samples are mounted as shown in Fig. 2 in a high pressure window bomb and uniform ignition obtained by using a strip of a double-base propellant. The combustion process is followed cinematographically using a 16 mm motion-picture camera. Two aspects of the combustion behaviour are shown in Fig. 2. Firstly the flame spread occurs around the oxidizer and then radial regression of the oxidizer particle occurs. Of course, the fuel also vaporises and contributes to the heat transfer processes. After combustion, the fuel

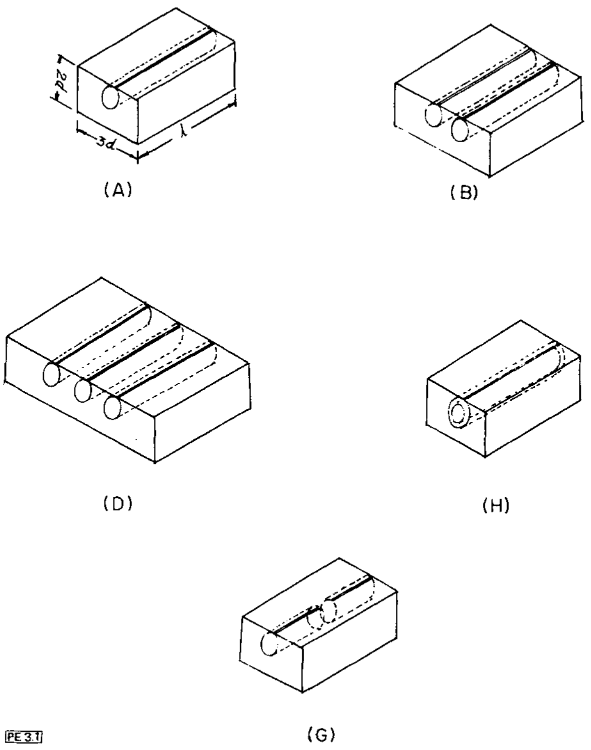

Figure 1. Various configurations.

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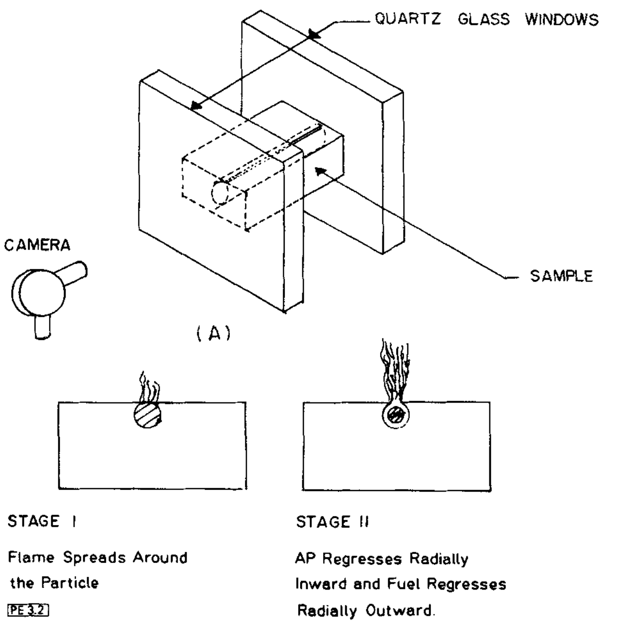

Figure 2. The experiment and the phenomenology of combustion.

block is taken out and the weight loss of the fuel is determined. From known weight of AP particle, the oxidizer-to-fuel ratio (O/F) is calculated. Corrections to weight loss due to residue of the double-base propellant are made with the help of auxillary tests on the double-base propellant alone. The pressure range of the tests is 10 atm–30 atm.

With regard to flame-spread effects, it was found that signiticant consumption of AP would occur only after the flame had spread. The flame-spread rate was found to be higher than the burning rate by a factor of 20 at least. Fig. 3 shows the details of the burning rate versus pressure for several of the cases listed in Fig. 1. It is noted that in all configurations in which AP pellet is in contact with the fuel (configurations A, B and D), the regression rate of AP in the model propellant is lower than that of AP alone. This is possible because the fuel acts as a heat sink extracting some heat from the flame. This result is in conformity with the results from sandwich propellants of Varney and Strahle[2]. The AP burning rate which is valid up to 22 atm has been extended to lower pressures in the sense of "free pyrolysis" as discussed by Lieberherr[3]. It is clear that below the low pressure deflagration limit (22 atm), the combustion of AP is due to the enhanced heat transfer from the

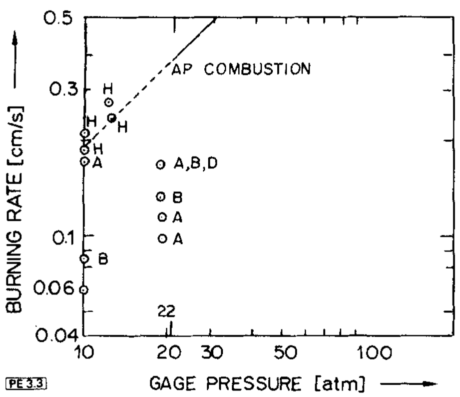

Figure 3. The burning rate versus pressure for CTPB/AP system. (Letters adjacent to the data points indicate the configuration.)

Table 1. Results.

Test No.	Gauge pressure [kg/cm²]	O/F	l [cm]	X_1, X_2, X_3 [mm]	Burning rate [cm/s]	Average burning rate [cm/s]
Group A						
A 1	10	5.09	1.75	–		0.152
A 2	10	3.09	1.80	–	0.152	
A 5	20	–	1.50	–	0.089	
A 6	20	2.81	1.25	–	0.114	
A 7	20	1.70	0.90	–	0.105	
A 8	20	–	1.25	–	0.169	
A 9	20	4.67	1.50	–	0.137	0.1228
Group B						
B 1	10	1.44	1.00	1	0.075	
B 2	10	–	1.70	2	0.079	0.077
B 3	20	7.07	1.15	1	0.163	
B 4	20	4.62	1.15	0.5	0.126	0.1445
Group D						
D 1	10	1.26	1.75	1, 1	0.059	
D 2	10	2.35	1.05	1, 1	0.091	0.075
D 3	20	2.97	1.40	0.5, 0.5	0.109	0.109
Group H						
H 3	10	20.19	2.50	2.0	0.137	
H 4	10	27.93	1.25	2.5	0.207	
H 5	10	14.14	2.05	1.8	0.209	
H 6	10	47.36	1.25	2.8	0.203	
H 7	10	22.40	1.75	2.0	0.234	0.1896
H 9	15	51.32	2.05	3.0	0.219	
H 10	15	42.37	1.8	2.8	0.290	
H 11	15	15.11	1.35	1.8	0.233	0.247

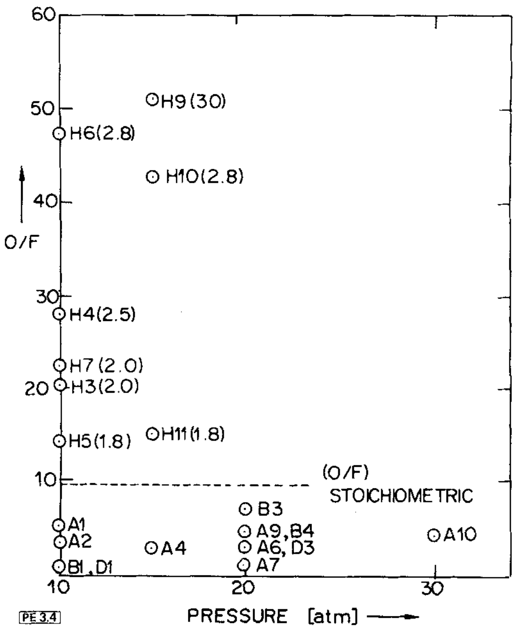

Figure 4. O/F versus pressure for various configurations.
(Letters adjacent to the data points indicate configuration; numbers in parenthesis indicate the separation distance in mm between fuel and oxidizer.)

diffusion flame. Some of the results obtained are tabulated in Table 1. A check on the average burning rate of AP in each of the above configurations indicated that this average remains fairly constant, irrespective of the configuration (especially for tests at 10 atm). There is thus no discernible correlation of the AP burning rate in the model with

(a) different particle-particle distances,
(b) length of pellets or
(c) number of neighbouring particles.

This observation points out to the possible independence of combustion of individual AP particle-ambient fuel units.

The data on O/F as a function of pressure are shown in Fig. 4. It is seen that fuel-rich combustion occurs in all the configurations in which the oxidizer and the fuel are in contact. In the configuration G, the contact area of the fuel-oxidizer interface was varied. Variation of this area over a wide range produced no discernible correlation with O/F. It was next thought worthwhile to examine the effect of separating the fuel and oxidizer by a small distance. Type H is of this kind. The results from these samples show that the burning rate of AP matches or marginally exceeds the "extended" burning rate of AP alone (cf. Fig. 2). The O/F in these cases as seen from Fig. 4 is clearly above the stoichiometric value. Fuel pyrolysis in this configuration is less than that in the previous configurations simply by virtue of the separating distance. The wide scatter in the values of O/F don't need to be alarming because in these tests, H_3-H_{11}, the separation between the oxidizer and the fuel varied from 0.8 mm to 3 mm as shown in the Figure itself. The same is true of the other tests A, B and D as the separation distances between oxidizer particles vary. Tests were made with a non-monopropellant oxidizer (potassium perchlorate (PP)-CTPB system) with the thought that the above result could be due to the monopropellant character of AP. These tests showed that combustion was sustained all through (burning rate of 0.079 cm/s at 10 atm). Tests with oxidizer being the same and fuel as polymethylmethacrylate (PMMA-AP system) showed that the O/F was higher than the stoichiometric value confirming the earlier result with CTPB-AP system.

Summarizing, the experiments on these two-dimensional propellants using cylindrical oxidizer pellets seem to suggest that (1) regression of AP is less than that of pure AP in propellant-like configurations, (2) combustion tends to be fuel rich in propellant-like configurations and (3) the possibility exists of the independence of individual oxidizer particle-ambient fuel units in the combustion process.

References

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(2) A. M. Varney and W. C. Strahle, *Combustion Science and Technology 4* (5), 197–208 (1972).
(3) J. F. Leiberherr, *Twelfth Symposium (International) on Combustion,* the Combustion Institute, Pittsburgh, Pennsylvania, 1969, p. 533.

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