Depressurization Extinguishment of Composite Solid Propellants: Influence of Composition and Catalysts

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Theme

THE goal of this experimental program was to gain more information about the transient combustion mechanism by measuring the pressure history, flame and spectral behavior, and surface structure. The test runs were performed at an initial pressure of 90 bar with a variation in the depressurization rate from − 1000 bar/sec through − 70.000 bar/sec.

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The experimental setup has been described elsewhere in detail.[1,2] A window-bomb (internal pressure up to 200 bar) was used with an internal volume of the combustion chamber of 135 cm.[3] The pressure release nozzle diameter varied from 2–25 mm closed by a double diaphragm during steady-state condition. The burning surface of the propellant was 1.5 cm × 3.5 cm. The influence of the initial pressure (23–90 bar) was studied previously[1,2] for some types of propellants. Now, the composition of the propellants was varied in a broad range as indicated in Table 1. The existing theories for the depressurization extinguishment, e.g., Refs. 3 and 4, depend on global assumptions and measurements. In order to gain more detailed information the experiments were focused on the participation of the condensed phase in the postreaction during transient.

At the highest depressurization rates, a postreaction of the condensed phase in the order of 2 to 5 msec was estimated. The oxidizer particles rested on the surface in dips (in the case of PBCT and PBAN) resp. surmounted the PU-binder. At the lowest depressurization rates, the small and medium particles were consumed leaving more binder area on the surface than due to the mixture ratio. Surface layers in the order of 100 μm were consumed during extinguishment. The final flame quench was due to fuel richness.[5]

The flame consisted of three phases (see Fig. 1): cessation of the steady-state flame (within 0.5 to 2 msec), dark period (2 to 5 msec), and redevelopment of a second flame at low pressure (duration 5 to 200 msec). Coarse propellants stop faster the first flame and restart more slowly the second one. The addition of aluminum resulted in a prolongation of the first flame and an earlier restart. The catalysts did not much alter the times nor did the change in the binder.

Plotting the initial depressurization rate vs the pressure at the final flame out (see Fig. 2) indicated the amount of postreaction. At very high rates the pressure drop could not immediately stop the gasification of the condensed material. At lower rates, the relaxation times of the gas expansion and the surface decomposition matched causing a flame-out at the highest momentary pressure. Further lowering of the rates enabled the development of the second flame.

Table 1 Composition of the propellants used

Type	AP in %	Particle size μm	PU	PBCT in %	PBAN	AL	Ferrocene	Copper Chromite	Iron Oxide	Carbon Black	LiF	Burning rate in mm/sec at 90 bar	Critical expansion rate in kbar/sec
1.1	76	5		24								26,4	8–20
1.4	76	100		24								8,5	5–11
1.5	76	200		24								8,6	5– 8
2.23	75,5	100		24			0,5					10,2	11–16
2.31	75,3	100		23,7				1,0				10,5	12–20
2.32	74,9	100		23,6				1,0		0,5		11,1	12–17
2.41	76	100		23,5					0,5			10,4	4–12
2.51	76	100		23,5							0,5	9,6	5–16
B × 7	76	5/200		24								10,1	6–14
B × 8	69,2	5/200		21,8		9						7,7	8–13
B × 13	62	5/200		19,5		18	0,5					9,1	26–35
ICRPG-Standard	75	200			23,5			1,0		0,5		8,9	2–4,4
PU	79	150	21									6,4	7,6–3

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Index categories: Combustion in Heterogeneous Media; Solid and Hybrid Rocket Engines.

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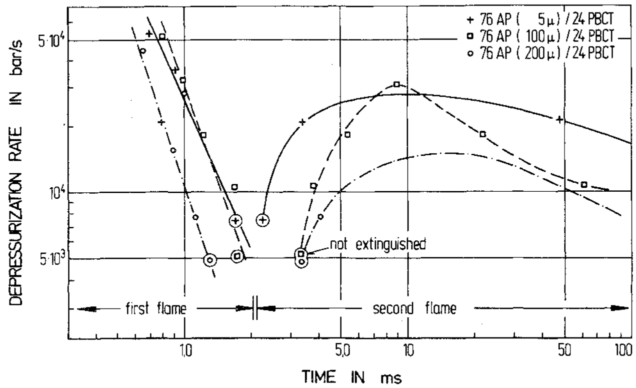

Fig. 1 Flame characteristics of composite propellants during depressurization; initial pressure: 90 bar.

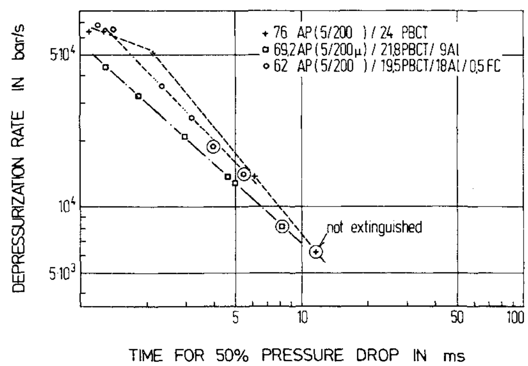

Fig. 3 Amount of postreaction during depressurization as shown by the shift of the time for a 50% pressure decay; initial pressure: 90 bar.

Another plot—the depressurization rate vs the time for a 50% pressure decay as shown in Fig. 3—illustrates the delays of the reaction even more clearly. In comparison to the expansion of an inert gas, the time for a 50% pressure decay will be extended by the short continuation of the gas reaction and the gasification of the condensed material. As the gas reaction will be at least 10^3 times faster than the condensed phase reaction all shifts in the plot of Fig. 3 can be attributed to a more intense decomposition of the surface layer after the initiation of the depressurization. Thus, the addition of 9% Al caused a rather rapid stop of the postreactions on the surface. This is in correspondence with the fact that the critical depressurization rate for the extinguishment was not changed in comparison to the nonaluminized propellant. The high aluminum content of 18% increased the postreaction time and also the critical depressurization rate (see Table 1). Here, the agglomeration of molten Al particles on the surface has to be considered. The shorter postreaction time in comparison to the nonaluminized propellant can be interpreted by the lower AP-content of the propellant. It was noted that the oxidizer content had the strongest influence on these postreaction times. Within the particles size distribution, the smallest particles had a slightly greater influence than the bigger ones. This finding is in correspondence with the burning rate (see Table 1). The change in the binder gave nearly the same results. PBAN stopped faster than PBCT and PU faster than PBAN, but the differences are not very significant. Thus, the interpretation must be an easier pyrolysis of the PU-binder. It was further noted that all 5 catalysts used did not alter the postreaction time. Hence there was no direct influence on the condensed phase.

The greatest differences showed up in the values for the critical depressurization rate for the extinguishment (see Table 1). The tendencies were: 1) particle size: 5 μ needed higher $-dp/dt$ than 200 μ; 2) catalysts: LiF and iron oxide had no influence, ferrocene and copper chromite needed higher $-dp/dt$; 3) aluminum: 9% had no influence, 18% needed extreme high $-dp/dt$; and 4) binder: easiest extinguishment with PU, next was PBAN, then PBCT.

The reported investigations indicate a significant postreaction of the condensed phase during the depressurization period. But this seems to be of minor influence as shown by the behavior of catalyzed propellants. The more important steps seem to be the easiness of gas reactions—thus leading to a more intense energy feedback—and the decomposition mechanism of the binder. The later one should be more closely investigated.

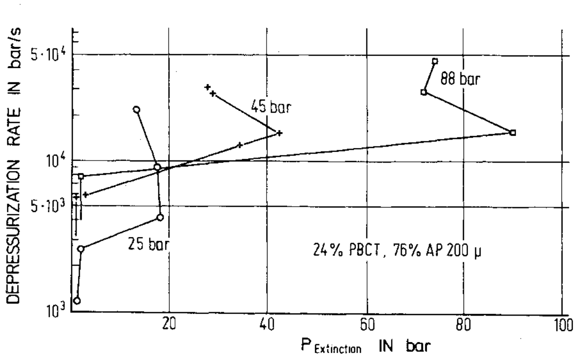

Fig. 2 Dependence of the pressure level at the final flame out; initial pressure was 25 bar, 45 bar, and 88 bar.

References

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