Preheating Slow-Burning Pyrotechnic Compositions to Aid Ignition and Combustion

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Abstract

A PROPOSAL is made to preheat the unburned mixture ahead of the reaction front in slow-burning pyrotechnic compositions by incorporating heat-conducting rods parallel to the direction of flame propagation. The objective is to enhance the reliability of ignition transfer and prevent flame quenching in marginally combustible mixtures. A Bruceton analysis of the results of a gap test on a slow-burning pyrotechnic composition, with and without heat-conducting rods, indicates that the mean gap for successful ignition transfer can be increased by almost an order of magnitude by incorporating the heat-conducting rods.

Contents

There are many items of ordnance stores that use slow-burning pyrotechnic compositions. Some common examples of these are long-burning marine location markers and other types of smoke-producing candles. In these applications, the pyrotechnic composition is intentionally made lean to achieve slower burning and accommodate higher loading of smoke-producing material. The formulation obviously leads to lower combustion temperatures, and in many cases, flame extinction due to quenching of the chemical reaction as temperatures fall. Flame propagation across increment interfaces in such candles may also be unreliable.

It is well known that both ignition and combustion are assisted by preheating a chemically reactive mixture. An increase in temperature reduces the ignition delay and increases the rate of burning. It also broadens the flammability limits. These facts are well exemplified in Weinberg's "excess enthalpy burners" where some product enthalpy is "borrowed" to preheat the reactants.[1] By this method, Weinberg has demonstrated that very lean fuel/air mixtures can be burned successfully.[2] In these gas burners, the reactants are preheated by jacketing them with the products of combustion. However, such a method is not suitable for use with solid pyrotechnic mixtures. It was therefore decided to investigate whether it was feasible to preheat slow-burning pyrotechnic mixtures by incorporating heat-conducting metal rods parallel to the direction of flame propagation in order to transfer thermal energy ahead of the reaction front.

A theoretical analysis of the heat flow through a slender rod, embedded in a pyrotechnic mixture through which a combustion wave advances with a steady velocity v, was made on the lines suggested by Rosenthal.[3,4] Figure 1 is the defining sketch of the problem.

The temperature-time history of locations along the rod ahead of the reaction front is given by

$$\frac{t-t_{s_2}}{t_{s_1}-t_{s_2}} = \frac{\lambda_1-\beta v}{\lambda_1+\lambda_2}\cdot\exp[-(\lambda_2+\beta v)\xi]$$

and the rate of heat transfer through the rod at the reaction front by

$$q_0 = kA\frac{(\lambda_2+\beta v)(\lambda_1-\beta v)}{(\lambda_1+\lambda_2)}(t_{s_1}-t_{s_2})$$

where

ξ = coordinate with respect to axis moving with the combustion wave; $\xi = x - v\tau$, τ = time
λ = $\sqrt{(\beta v)^2+m^2}$
β = $½\alpha$; α = thermal diffusivity of rod
m = $\sqrt{hP/kA}$; h = surface heat transfer coefficient, reciprocal of contact resistance; P = perimeter, k = thermal conductivity, A = area of cross section of the rod
t = temperature of rod; function of ξ
t_s = temperature of mixture surrounding rod

Subscripts 1 and 2 represent values behind and ahead of the reaction front, respectively.

Figure 2 shows the temperature distribution for a 1-mm-diam rod of copper ($k = 400$ W/mK; $\alpha = 117\times10^{-6}$m^2/s),

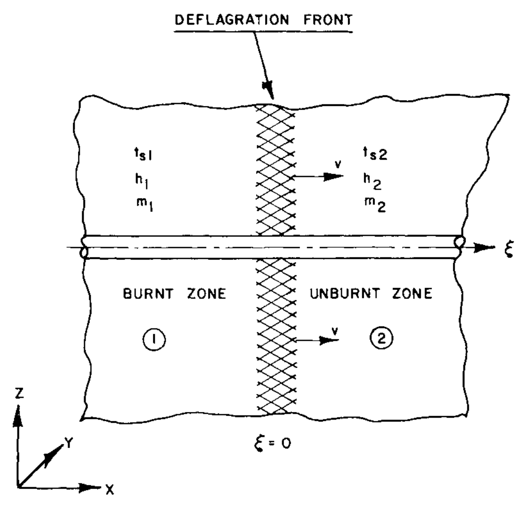

Fig. 1 Transient conduction in a slender rod.

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Table 1 Gap test for ignition transfer—Bruceton method[a]

	Donor-acceptor, 10 mm diam.			Donor-acceptor, 16 mm diam.		
	0 rods	1 rod	4 rods	0 rods	1 rod	4 rods
50% reliable distance $\bar{X}$	2.54	8.7	18.74	7.7	49.63	59.11
Standard deviation, σ	1.02	0.76	1.19	1.66	0.64	0.62
Sampling error, $S_{\bar{X}}$	0.25	0.19	0.29	0.4	0.16	0.16
Sampling error, S_σ	0.51	0.34	0.63	1.04	0.27	0.26

[a]All distances in mm/s.

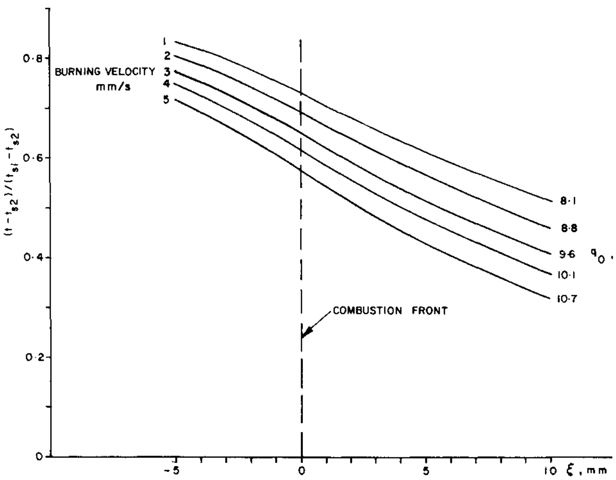

Fig. 2 Analytical results.

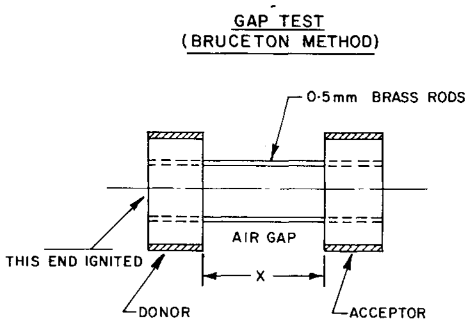

Fig. 3 Gap test for ignition transfer.

with h_1 and h_2, the surface heat transfer coefficients in the burned and the unburned zones equal to 1000 W/m^2 and 100W/m$^2\cdot$K, respectively, for various values of the burning velocity v. The rates of heat flow in the rod toward the unburned zone are also shown.

It can be seen that the temperature rise along the rod can be a significant fraction of the temperature rise due to combustion. This can provide local "hot spots" to assist ignition transfer and ensure an uninterrupted flame propagation.

A few preliminary experiments have been conducted on the gap test for ignition transfer in donor-acceptor pairs of a slow-burning pyrotechnic composition (1 – AAQ dye 30%, potassium chlorate 38%, lactose 12%, sodium bicarbonate 2%, binder 18%; by weight) with and without heat-conducting rods embedded in them. Figure 3 is a schematic diagram of the experimental setup. The results of a Bruceton analysis[5] of the experimental data are presented in Table 1.

Conclusion

The temperature rise along a conducting rod embedded in a slow-burning pyrotechnic mixture can attain a significant fraction of the temperature rise due to combustion. The experimental results confirm that, by this method, it may be possible to improve the reliability of ignition and combustion of marginally combustible mixtures.

Acknowledgment

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