Changing the Standards for Promoted Combustion Pass/Fail Criteria

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A standard test for determining metals flammability in enriched oxygen is the American Society for Testing and Materials (ASTM) G124 *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen Enriched Atmospheres*. Promoted ignition testing determines the relative flammability of metals in oxygen-enriched atmospheres. The results of the tests are generally published as the threshold pressures or the lowest pressure in 100% oxygen that supports combustion of a metal test sample. Currently, the standard defines combustion as consumption of an entire 150-mm (5.9-in.)-long, 3.2-mm (0.13-in.)-diameter rod. However, the credibility of an entire rod burning to determine flammability has been questioned. Differences in interpretation of the burn criteria led to inconsistent ranking of materials at various test facilities. Therefore, NASA White Sands Test Facility (WSTF) initiated a study to help define the burn length criteria used for determining threshold pressures.

Promoted ignition testing determines the relative flammability of metals in oxygen-enriched atmospheres (ASTM G124). The burning promoter that ignites the metal rod has an incidental preheating effect on the test sample. WSTF performed experiments to determine the promoter heat affected zone (HAZ), which is the distance heated by the promoter just before its detachment or consumption. Based on the HAZ determined, 30 mm (1.18 in.) of rod must be consumed before the material should be considered flammable. This finding has modified historical views of metals flammability in the specific application of ASTM G124 and other tests. ASTM G124 is currently being revised and will incorporate these pass/fail criteria.

To determine the HAZ, test sample configurations replicated ASTM G124, except thermocouples were inserted along the sample at various depths and intervals. WSTF is equipped with a test chamber that is used primarily for ASTM G124 standard promoted combustion testing. One of the chamber viewports was modified to incorporate multi-thermocouple temperature readings at test pressures up to 34.5 MPa (5,000 psi). Temperature and pressure data were recorded at 100 Hz. High-speed video established the event duration, which was the time from ignition of the promoter to the first significant drop of molten metal or promoter detachment or consumption.

Test samples were 305-mm- (12 in.)-long and 3.2-mm- (0.125-in.)-diameter copper rods. Commercially pure copper was chosen for its high thermal conductivity and resistance to burning at elevated pressures and concentrations of oxygen. Magnesium and aluminum promoters were ignited using Pyrofuze® wire. The test matrix is shown in Table 1.

Promoter Material	Pressure		No. of Tests
	MPa	psi	
Magnesium	0.7	100	1
Pyrofuze®	3.5	500	1
Magnesium	3.5	500	4
Aluminum	3.5	500	4
Magnesium	6.9	1,000	3
Aluminum	6.9	1,000	3
Magnesium	34.5	5,000	4
Aluminum	34.5	5,000	3

Table 1. *Copper rod test sample configuration and test matrix.*

Figure 1 shows a typical temperature vs. time plot for copper samples with aluminum promoters; vertical lines denote the beginning and end of event duration.

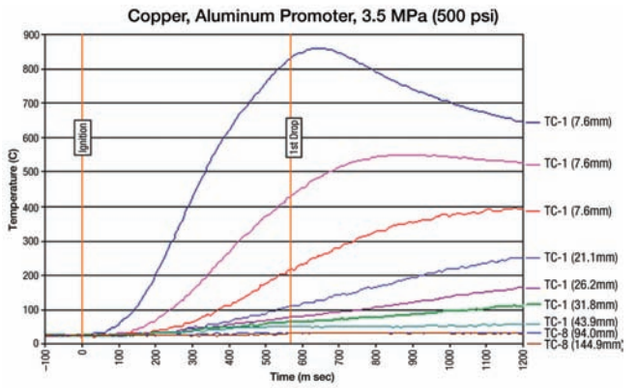


Fig. 1. *Typical time vs. temperature data, showing event duration.*

To determine the promoter HAZ, researchers must understand the amount of sample preheating, in terms

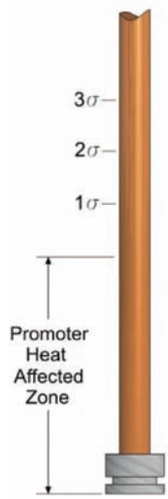
of temperature, necessary for the burning characteristics to be affected. Changes in flammability are noted by changes in either the *pressure* at which a metallic sample will support burning or the *rate* at which the sample melts while it is burning; both are indicators of metals flammability and are used historically to compare metals.

Temperatures at the end of the ignition events were used to determine the location, from the bottom of the rod, in which the samples reached 260°C (500°F). The data show that, including standard deviation (STDEV) error bars, the promoter HAZ did not extend beyond 17.8 mm (0.70 in.). This distance included the promoter engagement distance, which differs from ASTM G124 instructions.

The mean value and STDEV in the test pressure group with the largest promoter HAZ was found, and a 3-∑ distribution was applied using the Central Limit Theorem. Using the most severe condition (3.5 MPa (500 psi)) in heat generation/conduction, and combining both aluminum and magnesium promoter sample data, testing yielded a mean HAZ distance of 16 mm (0.63 in.) with an STDEV of 1 mm (0.041 in.). Applying three STDEVs resulted in a promoter HAZ of 19 mm (0.75 in.) from the bottom of the rod (figure 2).

Based on these data, which were also validated by thermal modeling, researchers discussed and decided that, within NASA, samples that burn more than 30 mm (1.18 in.) above the promoter (adding roughly 50% of the actual HAZ as a conservative buffer) will be considered a burn. Since most metals have a lower thermal conductivity than copper, this ensures that all metals that burn a distance > 30 mm (1.18 in.) are clearly burning independently of any promoter ignition effects. ASTM G124 is currently being revised and will incorporate these same pass/fail criteria.

The experimental observations and subsequent conclusion of the promoter HAZ study modifies the historical views of metals flammability in the specific application of ASTM G124 and other tests that often require that the test sample be consumed entirely or halfway to be considered flammable. This result is also specific to the igniter materials tested. Copper was chosen as the major test material based on several factors, most significantly its resistance to burning and high thermal conductivity. As the promoter in this experiment, HAZ is calculated using a 260°C (500°F) temperature bias. It should be noted that, with further research in respect to elevated temperature, the promoter HAZ may need to be modified accordingly.



Three Sigma HAZ 260 °C / 3.5 MPa	
HAZ (mm)	16.1
Sigma (mm)	1.0
HAZ+3(Sigma) (mm)	19.2

Fig. 2. *HAZ produced from ignition promoter after applying the Central Limit Theorem using a 260°C (500°F) temperature.*

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