PROMOTED COMBUSTION TEST DATA RE-EXAMINED

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ABSTRACT

Promoted combustion testing of metallic materials has been performed by NASA since the mid-1980s to determine the burn resistance of materials in oxygen-enriched environments. As the technology has advanced, the method of interpreting, presenting, and applying the promoted combustion data has advanced as well. Recently NASA changed the burn criterion from 15 cm (6 in.) to 3 cm (1.2 in.). This new burn criterion was adopted for ASTM G 124, *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres*. Its effect on the test data and the latest method to display the test data will be discussed. Two specific examples that illustrate how this new criterion affects the burn/no-burn thresholds of metal alloys will also be presented.

1 INTRODUCTION

NASA White Sands Test Facility (WSTF) has been performing promoted combustion/ignition testing for nearly 30 years. The data generated from these tests, and tests performed by several other laboratories, have led to a better understanding of materials' flammability, particularly metal alloys, in oxygen-enriched environments. Recently, the burn criteria used to determine the flammability of a material was changed by NASA and the ASTM Committee G-4 from 15 cm (6 in.) to 3 cm (1.2 in.), resulting in several metal alloys previously considered non-flammable at lower pressures being considered flammable. Two metal alloys affected by the new burn criteria are 300 series stainless steel and Inconel® 718. Both will be discussed further in Section 3. The current method of displaying and evaluating the promoted combustion data has also been modified and will be discussed in Section 4.

2 BACKGROUND

The promoted ignition or combustion test determines the minimum test gas pressure that supports self-sustained combustion (the threshold pressure) of a standardized sample of a metallic material. The standard test sample is suspended vertically from the top and has an energetic (typically aluminium or magnesium) promoter attached to the bottom to add supplemental heat and increase the temperature to start combustion. The data from this test provide a relative ranking of the burn resistance or flammability and establish a burn-no-burn threshold of the material. These results are utilized in the various communities that use oxygen-enriched environments. The NASA community applies the data in keeping with NASA Standard 6001, *Flammability, Offgassing, and Compatibility Requirements and Test Procedures* [1]. This standard states that if a material is determined to be flammable, an oxygen compatibility assessment (OCA) will be performed in accordance with NASA/TM-2007-213740, *Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems* [14], which evaluates the material's application in the worst-case environment in the intended use configuration. The results from this test are also used by other communities that utilize oxygen-enriched environments, and are referenced in various ASTM, CGA, and NFPA documents.

2.1 Test Method

The test method is described in NASA STD 6001, Test 17, *Upward Flammability of Materials in GOX* [1], as it is used for the NASA community. The NASA STD 6001, Test 17 document refers to the ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres* [2], for a general description of the test method and specifies certain exceptions to that test method for NASA use.

2.2 Test System and Sample Preparation

A typical promoted combustion test chamber (Fig. 1) has a maximum allowable working pressure (MAWP) of 79.2 MPa (11,500 psi). The gaseous oxygen used conforms to the requirements of MIL-PRF-27210G [9]. The purity must be greater than 99.5 percent. Test samples are cylindrical rods that are 0.32 cm (0.125 in.) diameter and between 10.2 cm (4 in.) and 30.5 cm (12 in.) long. A promoter, typically aluminium or magnesium, is applied to the bottom of the test sample to start the combustion of the material. The test sample is held at the top of the sample mount as seen in Fig. 1. By electrically heating an aluminium-palladium wire that is wrapped around the promoter, the promoter is ignited.

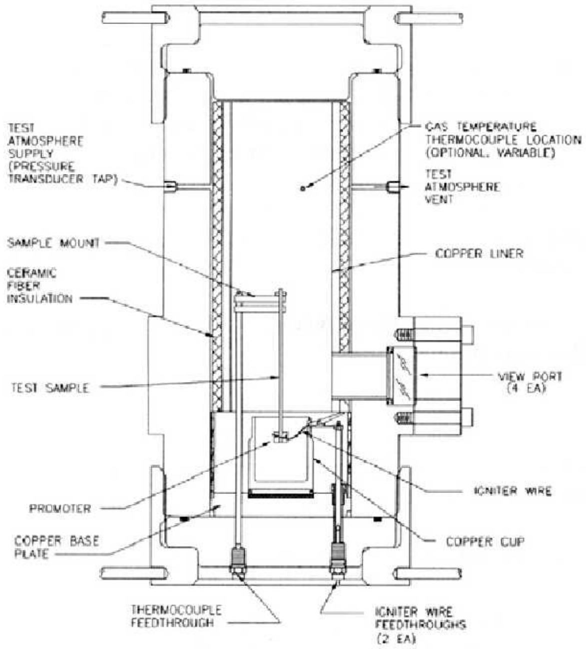

Figure 1. Mounted Test Sample in Promoted Combustion Test Chamber [15]

ASTM G124 requires that there are five “no-burn” tests for a material to be considered non-flammable, and NASA-STD-6001 requires ten tests. For a material to be considered flammable, only one burn is required at any given pressure.

3 NEW BURN CRITERION

A study was performed by Sparks et al. to better understand the preheating effect of the promoter on the sample rods. They established the heat affected zone (HAZ), the length of the test sample that is preheated during the time that the burning promoter remains attached to the rod after ignition. They concluded that the maximum HAZ for the most conductive test material (copper) was 1.9 cm (0.75 in.) from the bottom of the test sample [3]. As a result of statistical variance, analysis by other authors [4], and extensive discussion within the NASA community, a new burn criterion of 3 cm (1.2 in.) was established. This change in burn criterion from 15 cm (6 in.) to 3 cm (1.2 in.) will affect the threshold pressures at which metal alloys are considered to be flammable.

3.1 Examples

The effect of the new burn criterion on the flammability of two metals, 300 series stainless steel and Inconel®[1] 718, are discussed here.

3.1.1 300 Series Stainless Steel

Using the old criterion of 15 cm (6 in.), 300 series stainless steel was considered flammable at pressures greater than or equal to 500 psia because it burned 16.3 cm (6.3 in.) at that pressure [10]. Using the new criterion, 300 series stainless steel is considered flammable at 200 psia because it burned 3.4 cm (1.3 in.) at that pressure [11]. Tab. 1 shows the pressures at which 300 series stainless steel was found to be flammable using the old and new criteria.

Table 1. Flammability of 300 Series Stainless Steel

Material	*Previous Criteria* Lowest Burn Pressure MPa (psia) [10]	*New Criteria* Lowest Burn Pressure MPa (psia) [11]
300 Series SS	3.4 (500)	1.4 (200)

3.1.2 Inconel 718

Tab. 2 shows the pressures at which Inconel® 718 was found to be flammable using the old and new criteria. Using the old burn-length criterion, multiple test samples of Inconel® 718 burned greater than 15 cm (6 in.) at 1000 psia, making it flammable at pressures greater than or equal to 1000 psia [12]. Using the new criterion, Inconel® 718 is considered flammable at 400 psia [13].

Table 2. Flammability of Inconel® 718

Material	*Previous Criteria* Lowest Burn Pressure MPa (psia) [12]	*New Criteria* Lowest Burn Pressure MPa (psia) [13]
Inconel® 718	6.9 (1000)	2.8 (400)

3.2 Effect on Industry

When considered solely from a fire hazard viewpoint, the new burn-length criteria will have a positive effect on industry. Materials will now be found flammable at lower pressures than before. This will tend to make new oxygen systems more burn resistant, and therefore safer. On the other hand, the new burn criterion may also

[1] Inconel is a registered trademark of Special Metals Corporation, headquartered in New Hartford, NY.

compel some to re-examine older oxygen systems. This examination may reveal that flammability risks previously thought to be acceptable are no longer acceptable.

However, it must be remembered that just because a material is flammable does not mean it cannot be safely used in an oxygen-enriched environment. If the ignition mechanisms are known and controlled, then the flammable material can be safely used. This approach of controlling ignition mechanisms to ensure the safe use of flammable materials is very common. For example, most of the materials in our houses or workplaces are flammable in air (wood, clothing, carpet, leather, and even human bodies), yet we avoid fires by identifying and avoiding ignition mechanisms. This approach can be implemented to safely use flammable materials in oxygen-enriched environments. In fact, this is one of the underlying principles of NASA's *Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems* [14]. This fire risk analysis and control protocol requires the evaluation of a material's flammability in its end-use environment. If the material is deemed flammable, then the various ignition mechanisms present in the application must be evaluated. If no credible ignition mechanisms are found to be present, then the flammable material is allowed for use.

If industry were to adopt an approach like the one used by NASA, then the effect of the burn criterion would not be adverse. Instead, it would enable the use of materials in a safer manner.

4 METHOD OF DISPLAYING DATA

One of the largest published lists of flammability data for metal alloys is found in ASTM Manual 36. In the first edition of ASTM Manual 36 [16], the promoted combustion data were displayed under the heading of threshold pressure and described as the minimum pressure required for self-sustained combustion. The actual range of burn lengths of the individual samples tested was not included in the reported data. Because of the work cited in this paper, the promoted ignition data is displayed in ASTM Manual 36, 2nd edition, depicting the lowest burn pressure and highest no-burn pressure [8]. Materials with higher no-burn pressures are considered to be less flammable than materials with lower no-burn pressures. By distinguishing between lowest burn and highest no-burn pressures, the pressure at which a material configured as a standard test sample must be considered flammable can be determined.

Tab. 3 presents the promoted combustion data for which burn lengths of the specific test samples are known. It includes the number of tests that were performed at a specific pressure and the range of burn lengths observed for those tests.

It is obvious that for many materials included in Tab. 3, additional tests must be conducted to establish no-burn pressures that meet the ASTM G124 criterion of five tests and the NASA STD-6001A standard of ten tests. These tests will be conducted as the need for that data arises.

4.1 Transition Curve

The promoted ignition-combustion transition (PICT) curve (Fig. 2), first published by Zawierucha et al. in 1991 [6], illustrates a transition zone where burn propagation of an ignited test sample is unpredictable and erratic [8]. It can be seen that as pressure increases, the transition a material makes from non-flammable to flammable is not abrupt.

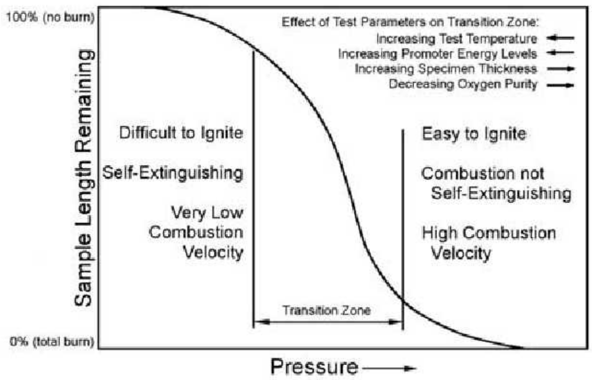

Figure 2. Schematic of the Promoted Ignition-Combustion Transition [8]

The upper shelf, or no-burn region, of the curve characterizes materials that are more difficult to ignite and are self-extinguishing if they do ignite. These are the more burn-resistant materials. Materials on the lower shelf, on the other hand, are more easily ignited and burning will propagate once the material is ignited. With the new burn criteria, the pressure at which the criterion is met will be toward the upper shelf region of the PICT. Many test parameters affect the PICT curve, such as rod thickness, temperature, promoter energy levels, and oxygen purity. The shape of the transition curve also varies for every material.

If funding were available, it would be desirable to conduct tests at several pressures spanning from the upper shelf, no-burn region, to the lower shelf, burn region. This sort of data set could be used to predict the threshold pressure of a material with higher precision. However, because of cost, this type of testing is not likely to be performed.

5 SUMMARY & CONCLUSION

A change in the burn criterion for the NASA STD-6001A, Test 17 and the ASTM G124 promoted combustion test has been made. The criterion was reduced from 15 cm (6 in.) to 3 cm (1.2 in.). This change was justified based upon measurement and analysis of the HAZ, which is the portion of the sample that is preheated by the burning promoter during the time it remains attached to the test sample. This change results in a lower flammability rating for many metals and metal alloys. For example, 300 series stainless steel, which was previously considered to be flammable at 500 psi, is now considered flammable at 200 psi. It is believed that this change will result in the design of more robust or burn-resistant components for use in oxygen-enriched atmospheres.

An updated data chart, previously published in ASTM Manual 36, includes recently obtained data. Many metal alloys presented in the chart do not have the required five no-burn test samples for ASTM or ten no-burn test samples for the NASA standard. Additional tests will need to be conducted to fill in this lack of data and this will be done as the need for that specific data arises.

6 REFERENCES

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11. Test Data Report Number WSTF # 06-40375, Test Data Report Number WSTF # 08-42997

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Table 3. Promoted ignition data for 0.32-cm (0.125-in.)-diameter metallic rods ignited at the bottom in stagnant oxygen. The data in this table ispresented in terms of "Lowest Burn Pressure" and "Highest No-Burn Pressure," and a burn is defined as consumption of ≥ 3-cm (≥ 1.2-in.) of the material above the promoter.

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source [a]
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
Brass 260	None				>72.4[b]	>10 500[b]	20	0.1-0.3	5.2	WSTF 09-43596
Brass 360 CDA	None				>72.4[b]	>10 500[b]	20	0.1-0.4	4.5-5.6	WSTF 09-43287/09-43439
Copper (commercially pure)	None				>72.4	>10 500[b]	20	0.1-0.2	5.1-5.2	WSTF09-43730
Nickel (commercially pure)	None				>68.9[b]	>10 000[b]	unknown		unknown	ASTM STP1267 p. 104
Platinum (commercially pure)	None				>68.9[b]	>10 000[b]	3	0.3	3	WSTF 94-28159
Gold (commercially pure)	None				>68.9[b]	>10 000[b]	3	0	unknown	WSTF 90-24243
Bronze C93600	None				>68.9 [b]	>10 000[b]	3	0.3-0.4	6	WSTF 92-26705
Silver (commercially pure)	None				>68.9[b]	>10 000[b]	3	0	6	WSTF 90-24243
Monel K-500	None				>68.9[b]	>10 000[b]	15	0.25-0.4	12.5	WSTF 89-22906, MAPTIS M105156-A47
Inconel MA754	None				>68.9[b]	>10000[b]	10	0.3-0.4	6.5	WSTF 88-22205 and MAPTIS 55748
Monel 400	None				>68.9[b]	>10 000[b]	13	0-0.4	6	MAPTIS 55695
Copper Beryllium	None				>68.9[b]	>10 000[b]	3	0-0.125	unknown	WSTF 86-20499
Nickel 200	None				>68.9[b]	>10 000[b]	20	0.1-0.3	12	MAPTIS 54195
Copper 102	None				>55.2[b]	>8 000[b]	2	0	5	ASTM STP910 p. 145
Red Brass	None				>48.3[b]	>7 000[b]	5	0.2	5	ASTM STP 986 p. 36
Tin Bronze	None				>48.3[b]	>7 000[b]	5	0.1	5	ASTM STP 986 p. 36
Yellow Brass	None				>48.3[b]	>7 000[b]	5	0.2	5	ASTM STP 986 p. 36
Zirconium Copper	None				>33[b]	>4800[b]	40	0.3	6	WSTF 06-40239
Silicon (commercially pure)	26.2	3800	1	1.25	20.7	3 000	1	0.75	5	WSTF 90-24252
Haynes 188	≤20.7[d]	≤3 000[d]	5	0.94-3.38	None				12.5	WSTF 89-22903
Haynes 242	≤20.7[d]	≤3 000[d]	5	2.5-5.25	None				12.5	WSTF 89-22904
Hastelloy C276	12.1	1750	3	≥1.16	10.3	1500	6	<1.16	4,8	ASTM STP 1111 p.257
Hastelloy C22	≤17.2[d]	≤2500[d]	10	0.4-5.8	None				12	MAPTIS 55795

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source [a]
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
Inconel 600	17.2	2 500	4	0.4-5.0	13.8	2000	11	0.1-0.4	12	WSTF 95-29293 and MAPTIS 10135/55441/55431
MP 35N	≤10.3[d]	≤1500[d]	5	0.3-3.0	None				12.5	WSTF 89-22899
Stellite 6	9.7	1400	2	0.5-1.4	8.3	1200	20	0.1-0.7	5.0-5.4	WSTF 08-42898/09-43459
Hastelloy Alloy G3	6.9	1 000	4	0-5	3.4	500	2	0.25-0.5	5	WSTF 89-22992
Incoloy 800	6.9	1000	2	1.1-5.0	3.4	500	5	0.4	5	ASTM STP 986 p. 36
Waspaloy	6.9	1000	4	0.8-5.8	3.4	500	3	0.8	5.8	MAPTIS 30125
Waspaloy (9110)	≤6.9[d]	≤1000[d]	6	0.2-3.6	None				5.6	WSTF 99-33689
Haynes 214[e]	≤6.9[d]	≤1000[d]	14	0.1-2.2	None				8.8	WSTF 98-33169
Colmonoy	6.9	1 000	1	2.4	3.4	500	5	0.25	5	WSTF[c]
Invar 36	≤6.9[d]	≤1 000[d]	6	3	None				3	WSTF 86-19834 /86-19840
Elgiloy	6.2	900	4	0.2-1.6	5.5	800	10	0.2-0.6	5.1-5.2	WSTF 09-43275
AL6 XN Stainless Steel	5.5	800	2	0.9-2.5	4.1	600	10	0.3-0.9	4.9-5.2	WSTF 08-43074
Inconel 625	4.1	600	7	0.3-1.3	3.4	500	20	0.1-0.8	5.1-5.2	WSTF 08-42897/09-43458
Chromium (commercially pure)	4.1	600	2	0-5	3.4	500	3	0	5	WSTF 92-26153
440C Stainless Steel	4.1	600	7	0.3-1.3	3.4	500	40	0-1.1	4.4-5.8	MAPTIS 30008/10106/50822/53129/ WSTF 09-43455
420 Stainless Steel	≤3.4[d]	≤500[d]	10	0-1.3	None				6	MAPTIS 54114/30136
422 Stainless Steel	≤3.4[d]	≤500[d]	10	0-1.3	None				5.8	MAPTIS 53537/54040
440A Stainless Steel	≤3.4[d]	≤500[d]	5	0-1.1	None				5.8	MAPTIS 30002
Inconel 718	2.8	400	13	0.2-1.4	2.1	300	20	0.2-0.6	12	WSTF 09-43671
17-4 PH	1.4	200	1	≥1.16	1	150	3	<1.16	3.87	ASTM STP 1111 p. 293
Lead (commercially pure)	3.4	500	2	0-1	2.8	400	1	0.5	6	WSTF 90-23860/88-22158/89-23425
Antimony (commercially pure)	3.4	500	3	0.5-2	2.8	400	1	0.25	5	WSTF 92-26468
Beryllium (commercially pure)	≤3.4[d]	≤500[d]	6	0-1.25	None				4	WSTF[c]
Ductile Cast Iron	≤3.4[d]	≤500[d]	1	5	None				5	ASTM STP 986 p. 36

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source [a]
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
Nitronic 60	2.1	300	1	1.2	1.4	200	25	0-1.1	3.5-4.9	WSTF 07-41733
9% Nickel Steel	≤3.4[d]	≤500[d]	1	5	None				5	ASTM STP 986 p. 36
Tin (commercially pure)	3.4	500	2	0-6	1.4	200	6	0	6	WSTF 89-23123/89-22728
15-5 PH Stainless Steel	2.8	400	1	1.2	2.1	300	20	0.2-0.8	5.1-5.2	WSTF 09-43453
Udimet 700	≤2.8[d]	≤400[d]	5	0-1.75	None				12.5	WSTF 89-22900
316 Stainless Steel	2.8	400	1	4.4	2.4	350	20	0.2-1.0	5.1-5.2	WSTF 08-42996/09-43460
Inconel X750	2.1	300	7	0.2-2.3	1.4	200	20	0.1-0.8	5.2	WSTF 09-43672
Zinc (commercially pure)	2.1	300	1	1.6	1.4	200	1	0.5	5.5	WSTF 90-24249
430 Stainless Steel	2.1	300	5	0.6-1.2	1.4	200	20	0.1-0.7	5-5.6	WSTF-09-43276/09-43440
Udimet 720	≤1.7[d]	≤250[d]	9	0.8-2.4	None				8.5	MAPTIS 55801
Aluminum-Bronze	1.7	250	2	0-6	1.4	200	1	0	6	WSTF 92-26731
316L Stainless Steel	1.4	200	22	0.1-1.3	0.8	111	20	0.1-0.9	5.2-6.3	WSTF 06-40375/08-42997
Inconel 800 HT	1.4	200	5	0.2-1.8	0.2	35	5	0.2-0.5	3.5	WSTF 98-33388
AMS 6278	1.4	200	2	0-5.5	0.7	100	5	0	5.5	WSTF 90-24243
Welda-lite 2195	≤0.8[d]	≤125[d]	10	0.2-5.1	None				12	MAPTIS 54314
Aluminum 1100	0.7	100	6	0-5	0.3	50	3	0-0.9	12	WSTF 88-21971
Molybdenum (commercially pure)	0.7	100	1	5.5	0.3	50	3	0	5.5	WSTF 90-24245
AISI 9310	0.7	100	2	0-5.5	0.3	50	3	0	5.5	WSTF 90-24233
Carbon Steel	≤0.7[d]	≤100[d]	3	>1.16	None				3.8	ASTM STP 1040 p. 44
Welda-lite 049	0.6	80	6	0.59-1.46	0.2	30	1	0.86	5	WSTF 89-23362
Iron (commercially pure)	≤0.5[d]	≤75[d]	1	5	None				5	WSTF 89-23136/ 89-23135
Tungsten (commercially pure)	0.17	25	1	2.2	0.09	12.4	1	0	3	WSTF 90-24247
Aluminum 2219	0.17	25	4	0-1.9	0.1	15	1	0.2	6	WSTF 89-23149
Vanadium (commercially pure)	≤0.17[d]	≤25[d]	1	2.6	None				5.5	WSTF 90-24248
Indium (commercially pure)	0.14	20	2	0-5	0.08	12.3	4	0-0.5	unknown	WSTF 92-26215
Aluminum (commercially pure)	0.09	12.4	1	2.93	None				3	WSTF 90-23856/90-23857

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source [a]
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
Tantalum (commercially pure)	>0.09[b]	>12.4[b]	3	0	None				unknown	WSTF 92-26424
Magnesium (commercially pure)	≤0.09[d]	≤12.4[d]	2	0-2.6	None				6	WSTF[c]
Ytterbium (commercially pure)	0.08	12	1	5	None				unknown	WSTF 92-26154
Aluminum 6061-T6	0.07	10	9	0-1.5	0.06	8	20	0-0.4	5-5.3	WSTF 09-43441
Hafnium (commercially pure)	≤0.06[d]	≤8[d]	1	5	None				5	WSTF[c]
Zirconium (commercially pure)	≤0.06[d]	≤8[d]	1	unknown	None				6	WSTF 88-22650
Titanium (commercially pure)	≤0.007[d]	≤1[d]	5	3.0-6.0	None				6	WSTF 88-21969
Ti-6A1-4V	≤0.007[d]	≤1[d]	4	unknown	None				6	WSTF 88-21970
Strontium (commercially pure)	≤Ambient Air[f]				None				unknown	ASTM STP1267 p. 104
Lithium (commercially pure)	≤Ambient Air[f]				None				unknown	ASTM STP1267 p. 104

[a]Sources of data include WSTF (White Sands Test Facility), MAPTIS, and ASTM Standard Technical Publications (STP). WSTF data are typically referenced by a WSTF number, and MAPTIS data are referenced by a specific material code.
[b]> indicates that this was the highest pressure tested and the material did not burn greater than 1.18-in.. The burn pressure, if it exists, is greater than the stated value.
[c]No WSTF number.
[d]≤ indicates that no tests were conducted at lower pressures and therefore the material may burn at pressures less than or equal to the stated value.
[e]The exact composition of this Haynes 214 alloy is unknown. Haynes 214 alloys have dramatically different results in this test depending on the specific alloy composition. For instance, while this unknown alloy burned greater than 1-in. at 1000 psi, Haynes 214 composed of 4.42% Al, <0.0025% B, 0.0370% C, 0.0081% Cb, 0.0075% Co, 15.16% Cr, 2.10% Fe, 0.1830% Mn, 0.0010% S, 0.0490% Si, and <0.0050%Mg, Mo, P, Ti, W, Y, and Zr with the balance being Ni did not burn greater than 1-in. in 10 tests in oxygen at 10,000 psi (WSTF 97-31129).
[f]Samples burned completely in ambient air at an atmospheric pressure of 85 kPa (12.3 psia).

Promoted Combustion Test Data Re-Examined

Michelle Lewis, Nathan Jeffers, and Joel Stoltzfus

Presented by: Michelle Lewis and Nathan Jeffers

Outline

- Introduction
- Background
  - Test Method
  - Test System and Sample Preparation
- New Burn Criterion
  - Examples
  - Effect on Industry
- Method of Displaying Data
  - Transition Curve
- Summary and Conclusion

Introduction

- NASA WSTF has over 30 years experience with promoted combustion/ignition testing
- NASA and ASTM recently changed burn criteria from 15 cm (6 in.) to 3 cm (1.2 in.)
- Current method of displaying promoted combustion (PC) data has been modified

Background

- PC test determines threshold pressure of standardized sample of metallic material
- Promoter used to start combustion of sample
- Data provides ranking of flammability and establishes burn-no-burn threshold of material
- Results used by various communities and referenced in ASTM, CGA, and NFPA documents

Test Method

- NASA STD 6001, Test 17, *Upward Flammability of Materials in GOX*
- Document refers to ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres,* for general description of test method

Test System & Sample Preparation

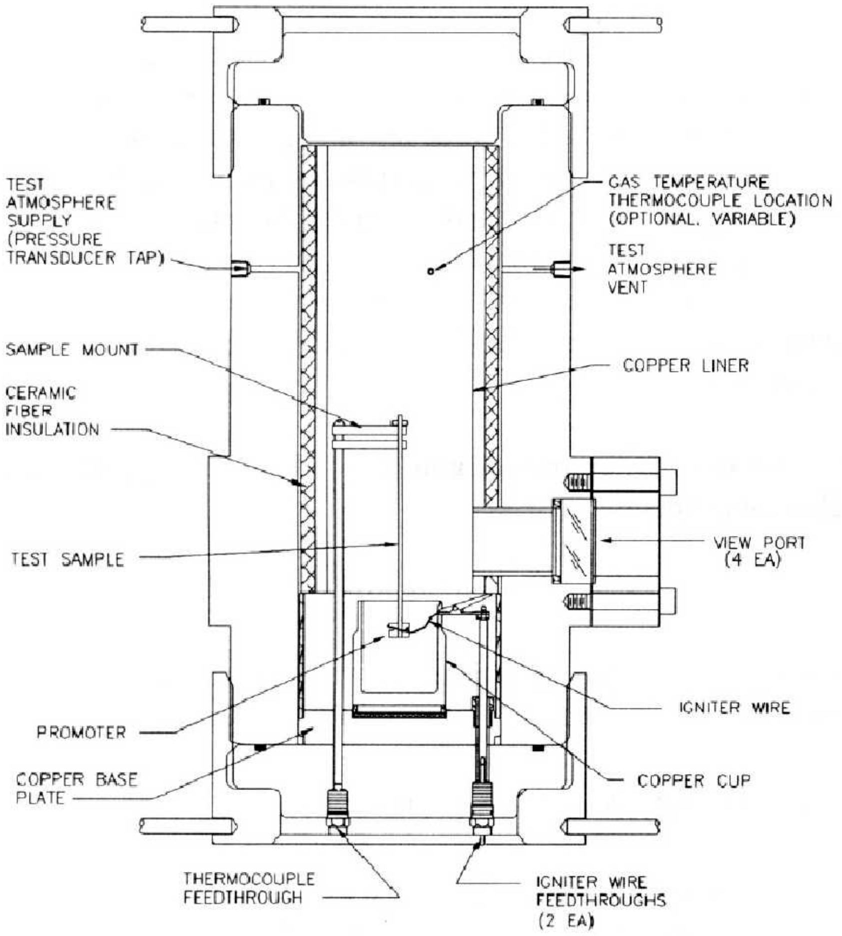
System:

- MAWP 79.2 MPa (11,500 psi)
- GOX MIL-PRF-27210G (99.5% pure or greater)

Sample Preparation:

- 0.32 cm (1/8 in.) Rod Diameter
- 10.2-30.5 cm (4-12 in.) Rod Length
- Al or Mg Promoter with Aluminum-Palladium Wire

Mounted Test Sample in Promoted Combustion Test Chamber



New Burn Criterion

- Study performed by Sparks et al. to understand preheating effect of promoter on sample rods
- Heat Affected Zone (HAZ) 1.9 cm (0.75 in.)
  - Old Burn Criterion 15 cm (6 in.)
  - New Burn Criterion 3 cm (1.2 in.)
- New burn criterion is now experimentally defined

Examples

- Flammability ratings of two metals were affected by the new burn criteria

Material	*Previous Criteria* Lowest Burn Pressure MPa (psia) [10]	*New Criteria* Lowest Burn Pressure MPa (psia) [11]
300 Series SS	3.4 (500)	1.4 (200)

  - At 3.4 MPa (500 psia), burned 16.3 cm (6.3 in.)
  - At 1.4 MPa (200 psia), burned 3.4 cm (1.3 in.)

Material	*Previous Criteria* Lowest Burn Pressure MPa (psia) [12]	*New Criteria* Lowest Burn Pressure MPa (psia) [13]
Inconel® 718	6.9 (1000)	2.8 (400)

  - At 6.9 MPa (1000 psia), burned >15 cm (6 in.)
  - At 2.8 MPa (400 psia), burned 3.6 cm (1.4 in.)

Effect on Industry

- New burn-length criteria will have positive effect on industry
- Oxygen systems will be more burn resistant and safer
- Burn criterion may require older systems be re-examined
  - Flammability risks may no longer be acceptable

Effect on Industry

- Flammable materials can be safely used in oxygen-enriched environments
  - Ignition mechanisms must be known and controlled
- Implement this approach to control mechanisms
- Underlying principle in NASA/TM-2007-213740, *Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems, Technical Memorandum*
- Industry needs to adopt approach, then effect of burn criterion would not be adverse

Method of Displaying Data

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
440C Stainless Steel	4.1	600	7	0.3-1.3	3.4	500	40	0-1.1	4.4-5.8	MAPTIS 30008/10106/50822/ 53129/ WSTF 09-43455
Inconel 718	2.8	400	13	0.2-1.4	2.1	300	20	0.2-0.6	12	WSTF 09-43671
15-5 PH Stainless Steel	2.8	400	1	1.2	2.1	300	20	0.2-0.8	5.1-5.2	WSTF 09-43453
Aluminum 1100	0.7	100	6	0-5	0.3	50	3	0-0.9	12	WSTF 88-21971

- Changed from threshold pressure – minimum pressure required for self-sustained combustion
- Currently lowest burn pressure and highest no-burn pressure

Method of Displaying Data

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
440C Stainless Steel	4.1	600	7	0.3-1.3	3.4	500	40	0-1.1	4.4-5.8	MAPTIS 30008/10106/50822/ 53129/ WSTF 09-43455
Inconel 718	2.8	400	13	0.2-1.4	2.1	300	20	0.2-0.6	12	WSTF 09-43671
15-5 PH Stainless Steel	2.8	400	1	1.2	2.1	300	20	0.2-0.8	5.1-5.2	WSTF 09-43453
Aluminum 1100	0.7	100	6	0-5	0.3	50	3	0-0.9	12	WSTF 88-21971

- Updated to 3.0 cm (1.2 in.)
- Currently lowest burn pressure and highest no-burn pressure

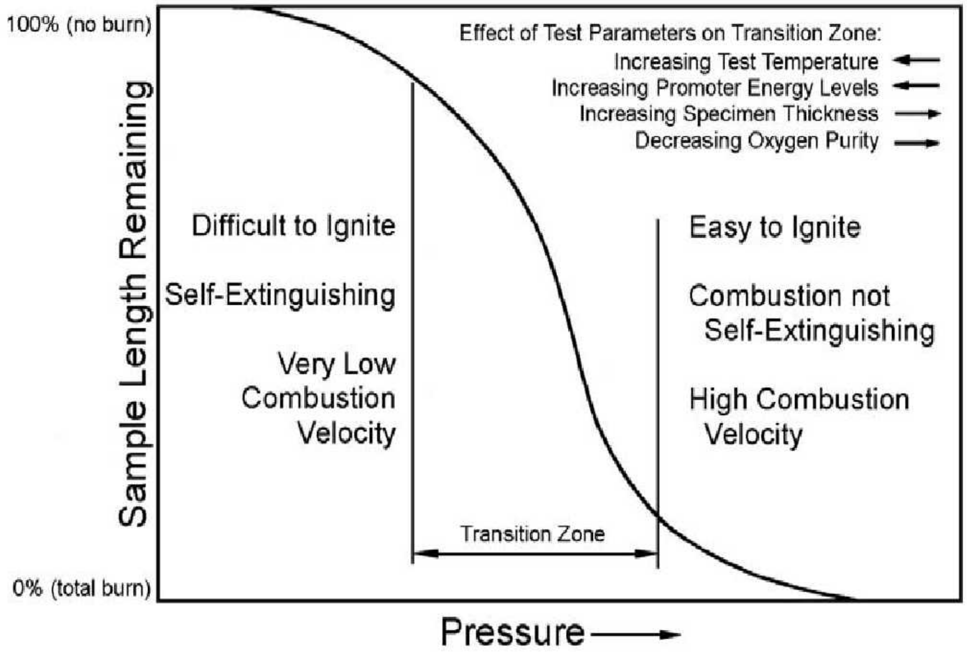
Method of Displaying Data

Material	Lowest Burn Pressure				Highest No-Burn Pressure				Rod Length (inches)	Source
	MPa	psia	# of Tests	Burn Length (inches)	MPa	psia	# of Tests	Burn Length (inches)		
440C Stainless Steel	4.1	600	7	0.3-1.3	3.4	500	40	0-1.1	4.4-5.8	MAPTIS 30008/10106/50822/ 53129/ WSTF 09-43455
Inconel 718	2.8	400	13	0.2-1.4	2.1	300	20	0.2-0.6	12	WSTF 09-43671
15-5 PH Stainless Steel	2.8	400	1	1.2	2.1	300	20	0.2-0.8	5.1-5.2	WSTF 09-43453
Aluminum 1100	0.7	100	6	0-5	0.3	50	3	0-0.9	12	WSTF 88-21971

- Additional tests needed to establish no-burn pressures
- ASTM G124 requires 5 tests and NASA STD-6001A requires 10 tests

Transition Curve

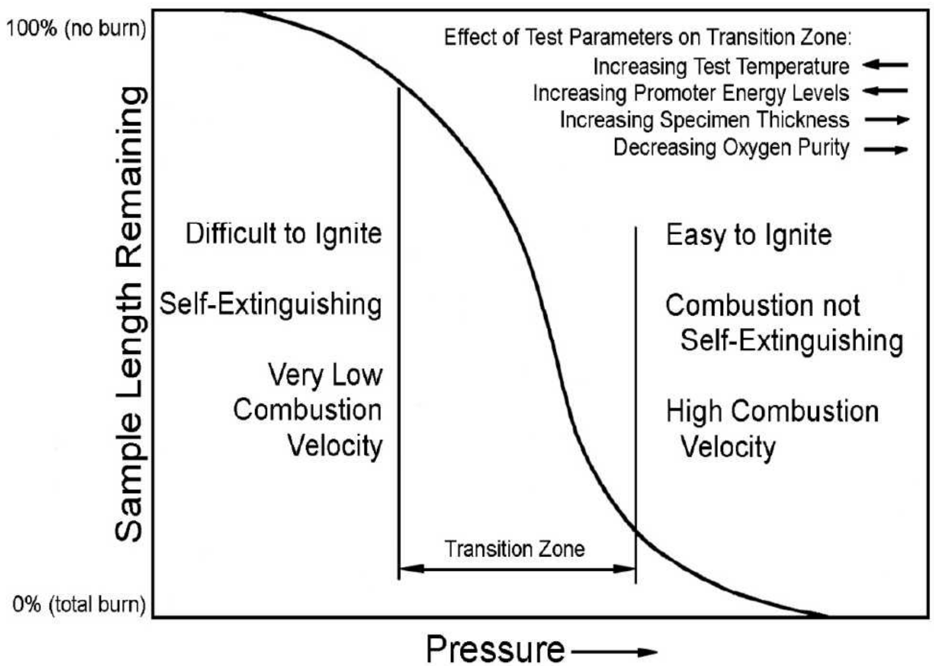
- PICT illustrates transition zone where burn propagation of ignited test sample is erratic and unpredictable
- Upper shelf – burn-resistant materials
- Lower shelf – easy to ignite



Schematic of the Promoted Ignition-Combustion Transition

Transition Curve

- Pressure toward upper shelf region for new burn criterion
- Parameters that affect curve:
  - Rod thickness
  - Temperature
  - Promoter energy levels
  - Oxygen purity
- Shape changes for every material



Schematic of the Promoted Ignition-Combustion Transition

Summary & Conclusion

- New burn criterion of 3 cm (1.2 in.) results in lower flammability ratings for metals and metal alloys
- Change will allow design of more robust components for use in oxygen-enriched environments
- Updated data chart also shows need for more data to be obtained to meet no-burn requirements