IDENTIFICATION OF AN ALTERNATE SUBSTRATE FOR TESTING REDUCED IGNITION PROPENSITY CIGARETTES

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ABSTRACT

Results from ASTM E2187, ISO 12863 and NZS/AS4830 for testing the ignition propensity of cigarettes have limitations that include sensitivity to mass, moisture content, and surface roughness of the filter paper substrate, variations in test results when using filter paper produced in a different location, and reliance on a proprietary product. Therefore identification of an essentially equivalent substrate with good reproducibility across various manufacturers and batches is underway. A summary of results of the initial screening and preliminary identification of a likely alternate substrate are presented.

INTRODUCTION

ASTM E 2187[1], ISO 12863[2] and NZS/AS4830[3,4] describe essentially the same test method for the ignition propensity of cigarettes. This standard test method is the basis for less fire-prone cigarette regulatory requirements in the U.S., Canada, Australia, and the European Union. U.S. fire incidence statistics project a likely reduction of roughly 30 % in deaths from cigarette-initiated fires.[5]

The regulations require that the lit sample-cigarette be placed on a specified number of layers of Whatman No. 2 filter paper[i] with the rough sides of the filter paper facing up. Testing is performed in a local environment (Figure 1a) where there is minimal disturbance of the air flow. The result recorded for each determination is whether or not a full-length burn of the cigarette is observed. Forty replicates are performed in a test. The number and percentage of full-length burns[ii] are reported. Examples of whether or not a full-length burn was observed are shown in Figure 1b.

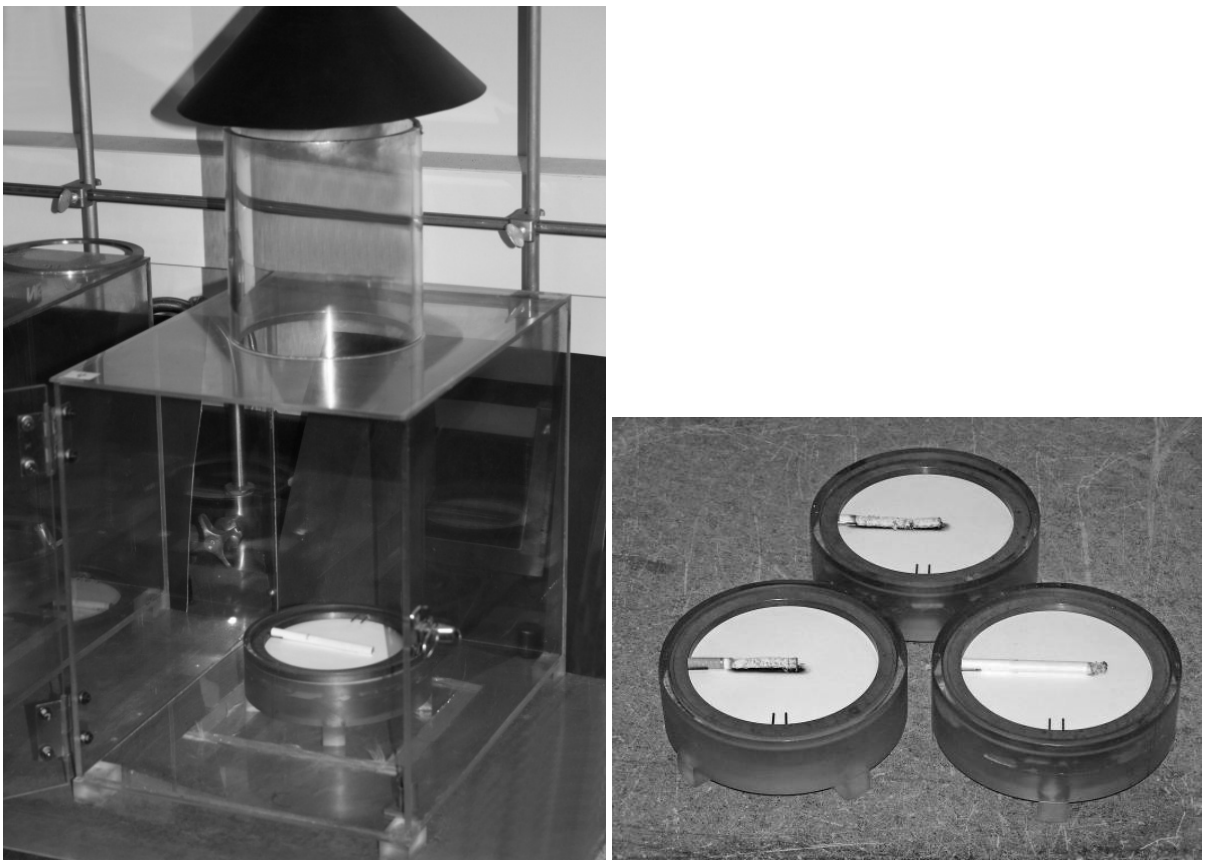
CURRENT SUBSTRATE

The choice of testing on 10 layers of this brand of filter paper resulted from a good correlation of test results with the ignition propensity of cigarettes as measured on upholstered chairs.[6] An interlaboratory study[6] determined values of intralaboratory repeatability, *r*, and interlaboratory reproducibility, *R*, which were later deemed useful for regulatory purposes.

[i] This commercial product is mentioned by name because it is explicitly required in the ASTM, ISO, Australian, and New Zealand standards. Such identification is not intended to imply BRANZ Ltd. or NIST endorsement of the product.

[ii] Percentage of full-length burns (PFLB) is not a standard unit. However, it has become the figure of merit used worldwide in this field of testing. This paper reports values in this form in the interest of facilitating communication to the intended audience.

Figure 1 Photograph of (a) a sample-cigarette being tested to ASTM E 2187, and (b) examples of full-length burns (top and left samples) and a non-full-length burn (right sample).



(a) (b)

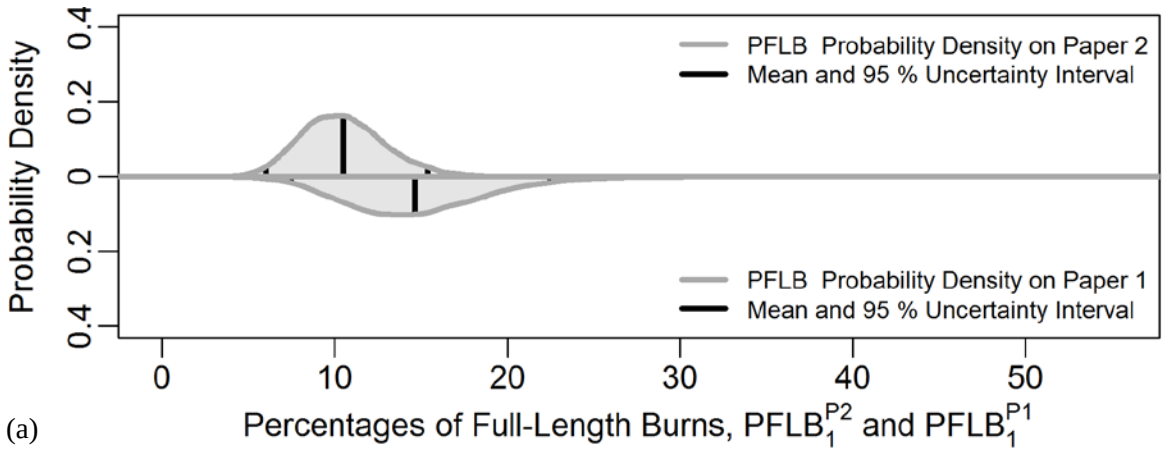
The 10 layers of filter paper[1-4, 7] act as a well-defined heat sink for the combustion enthalpy from the burning cigarette. A cigarette that keeps burning despite the heat loss is more of a fire threat than a cigarette that goes out due to the heat loss.

Despite years of relatively successful testing, there are potential limitations to the long-term reliance on this substrate.

- The test result is sensitive to substrate mass, moisture content, and surface roughness.[6]
- The test result is also likely dependent on other properties of the filter paper. For undetermined reasons, testing using other brands produced results that varied inconsistently for different cigarette designs.[6]
- It is undesirable to rely on a proprietary product.
    - Supply of the substrate has been previously limited.
    - As shown in Figure 2[8], potential performance differences were observed in nominally identical filter papers produced in the original location where Whatman No. 2 paper was manufactured and the new manufacturing location. Figures 2b and 2c show PFLB probability distributions values for testing on the two types of paper. The 95 % expanded confidence intervals do not, or only barely, overlap, indicating statistical differences in the performances of the two types of paper. In contrast, no performance difference is seen for the cigarette design shown in Figure 2a. This is a potential problem for both manufacturers and regulators.

In addition, routine testing consumes large quantities of the filter paper, both a cost and supply issue.

Figure 2 Comparison of the probability distributions for PFLB values on 10 layers of Whatman No. 2 filter paper produced at the current manufacturing plant (Paper 2) and the original manufacturing plant (Paper 1) for (a) Cigarette Design 1, (b) Cigarette Design 2, and (c) Cigarette Design 3.



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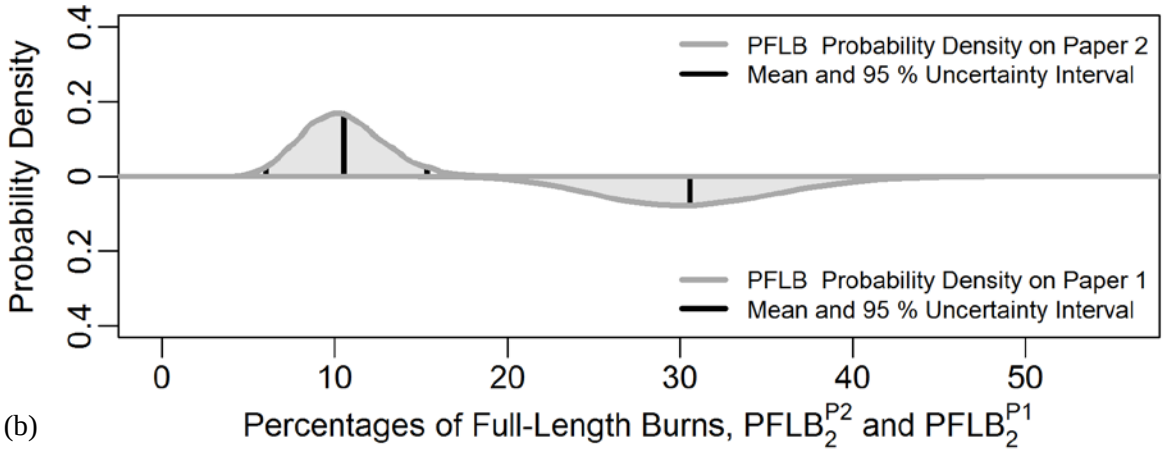

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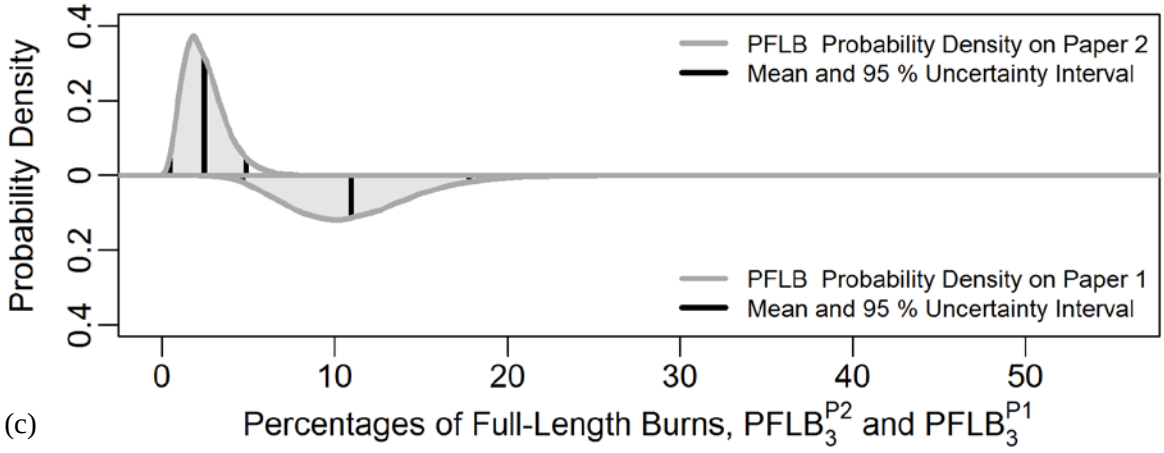


(c)

Therefore, it is desirable to identify a substrate that gives test results equivalent to those obtained using ten layers of Whatman No. 2 filter paper from the original manufacturing location. “Equivalent” means that the test results, the intralaboratory repeatability, and the reproducibility across laboratories and batches are all statistically indistinguishable from those obtained with ten layers of Whatman No. 2 filter paper from the original location. This is important, since the test method is used for regulatory purposes. Ideally, such a substrate would not be dependent on the crop of the agricultural material used in the paper and would be of low cost or reusable.

ALTERNATE SUBSTRATES – INITIAL SCREENING

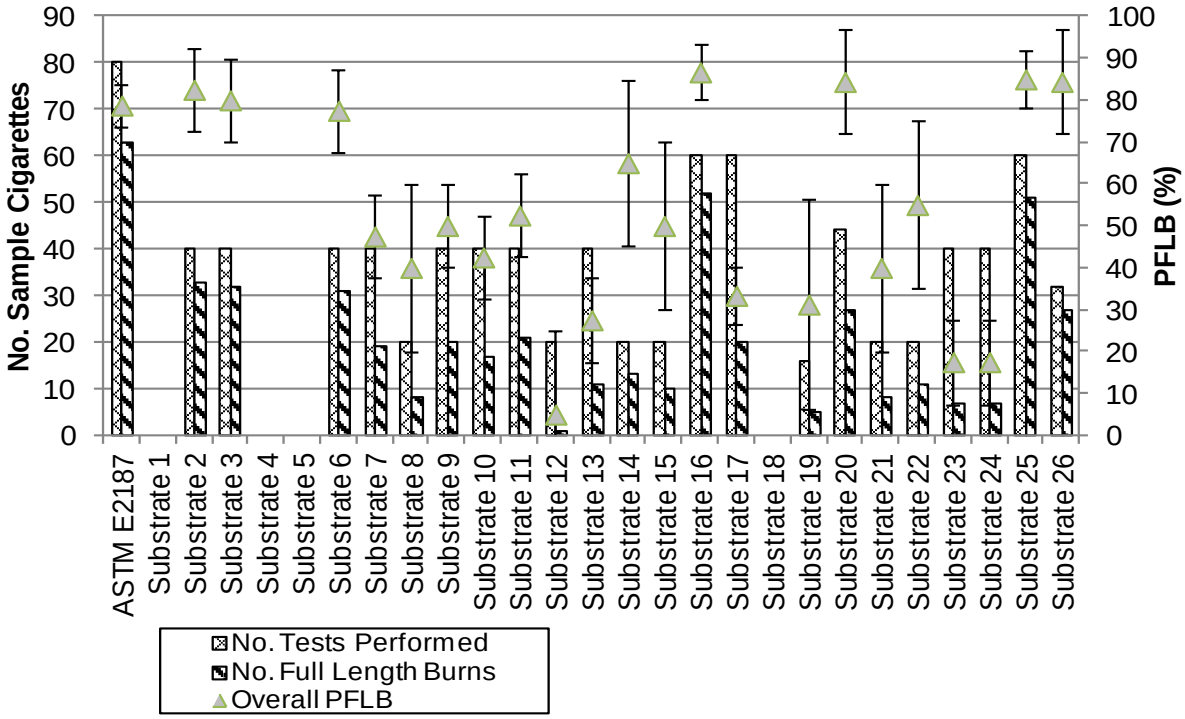
The starting hypothesis for the search for an alternate substrate was that the principal role of the original substrate was its behavior as a heat sink. Therefore, the search centered on identifying a material with a thermal inertia, equal to [thermal conductivity × density × specific heat]^{½}, comparable to the low value of the ten layers of filter paper. It was expected that the test results using a thermally thick material would be insensitive to the thickness of the substrate, while it would be necessary to control the thickness of a substrate that was thermally thin. Materials that were observed to distort, visibly char, or melt were eliminated.

Information for a broad range of potential materials was collated for consideration. The materials considered included glasses, other ceramics, papers, thermoset polymers, composite materials, metals and alloys, and combinations and thicknesses of these materials. Initial screening to remove outliers used a small number of replicate tests to record observations of the smoldering cigarette on the test substrate and whether or not any cigarette burned its full length. Table 1 summarizes typical test results for substrates that were not pursued further. Portrayal of the numbers of tests and percentages of full-length burns for a range of tested substrates compared to the results for the ten layers of Whatman No. 2 paper are shown in Figure 3.

Table 1 Examples of screened substrates and observations that resulted in identification as outliers.

	Material	Thickness	Summary of Test Observations that Resulted in Outlier Qualification
Thermally Thick	Polycarbonate	6 mm	0 PFLB, melt mark
	Polymethylmethacrylate	6 mm	0 PFLB, melt mark
	PTFE	6 mm	0 PFLB, melt mark
	Phenolic	6 mm	0 PFLB
	Assorted other polymers	Various	0 PFLB
	Brass plate	6 mm	0 PFLB
	Window glass	3 mm	0 PFLB
	Glass fiber/plastic	6 mm	0 PFLB
	Ceramic foam insulation	-	Too friable, porous
Thermally Thin	Glass	1.5 mm	0 PFLB
	Glass	0.4 mm	PFLB OK, fragile
	Glass fiber sheet	1.3 mm	Low PFLB
	Glass fiber sheet	0.7 mm	0 PFLB, substrate failure
	Glass cloths	Various	100 PFLB
	Ceramic sheet	1.6 mm	Low PFLB
	Aluminum foil	0.01 mm	100 PFLB, substrate failure
	304 stainless steel	0.1 mm	Low PFLB, substrate failure

Figure 3 Numbers of tests and PFLB values for a single cigarette design on a range of substrates.



ALTERNATE SUBSTRATE CANDIDATE – SUMMARY OF RESULTS

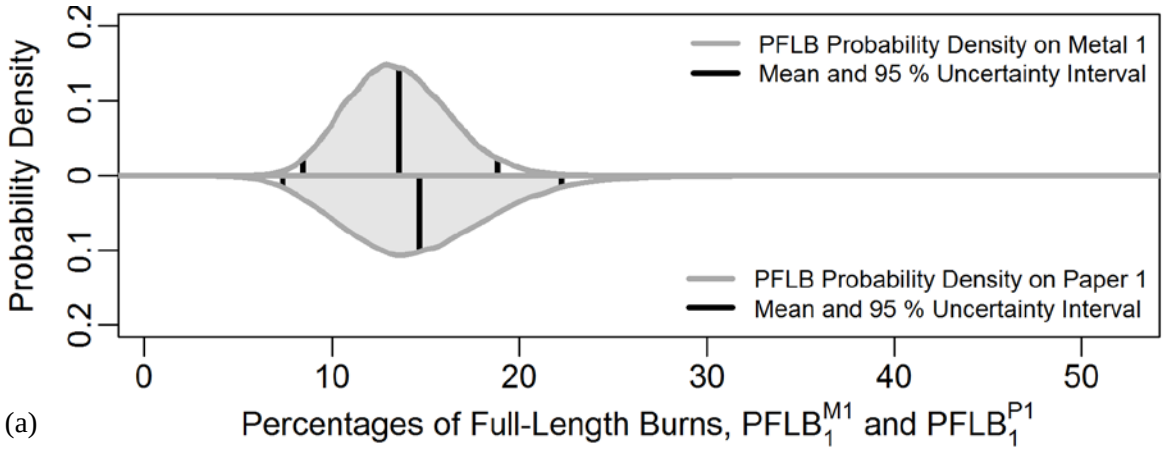
From these screening tests, two substrates emerged as meeting the selection criteria. One was a sheet of 0.4 mm thick glass with one layer of filter paper with the rough side up (Substrate 2 of Figure 3; substrate 3 is the same glass with the paper's smooth side up). The single layer of paper was included to wick away the moisture generated by the burning cigarette that was observed to condense at the interface of the cigarette and the relatively cool substrate (e.g., as observed in tests of Substrate 9 of Figure 3). However, there was concern for breakage and possible injury to the test operator. Thus, since there was a less fragile candidate identified, this substrate was not pursued further. (Substrate 1 is the ASTM E 2187 substrate cited in the cigarette regulations - 10 layers of Whatman No. 2 filter paper with the rough side up. No data were taken for substrates 4, 5, and 18 which were similar to other substrates that did not meet the selection criteria. Substrate 16 was not re-usable.)

The most promising candidate consisted of 0.2 mm thick 302 stainless steel (shim stock) with one layer of filter paper (Substrate 25 of Figure 3). The layer of filter paper was included for the same reason as with the glass substrate. (Compare the test results for Substrate 25 with the filter paper with those from Substrate 22 without the filter paper.) The stainless steel shim is a standard commercial product that can be readily cleaned and reused.

Further testing was carried out using stainless steel shim stock from three manufacturers, four brands of filter paper, and three different cigarette designs, with a larger number of replicate determinations (at least 80) of each combination. Because the steel shim stock is thermally thin, measurements were made at multiple locations on specimens from the three sources. The standard deviation of those measurements was less than 2 % of the mean.

Comparison of the PFLB probability distributions mean and statistical spread for one type of shim stock (Metal 1) and one layer of paper (Whatman No. 2, rough side up) with ten layers of Whatman No. 2 filter paper for three different cigarette designs are shown in Figure 4. The overlap of the 95 % confidence intervals for all three cigarette designs is an indication that the alternate substrate may well generate test results that are consistent with the original ASTM E 2187 test substrate of 10 layers of Whatman No. 2 filter paper. The agreement between is especially encouraging compared to the results in Figure 2.

Figure 4 PFLB probability distributions for one combination of shim stock (Metal 1) and paper (Whatman No. 2, rough side up) with the current ASTM E 2187 substrate for (a) Cigarette Design 1, (b) Cigarette Design 2, and (c) Cigarette Design 3.



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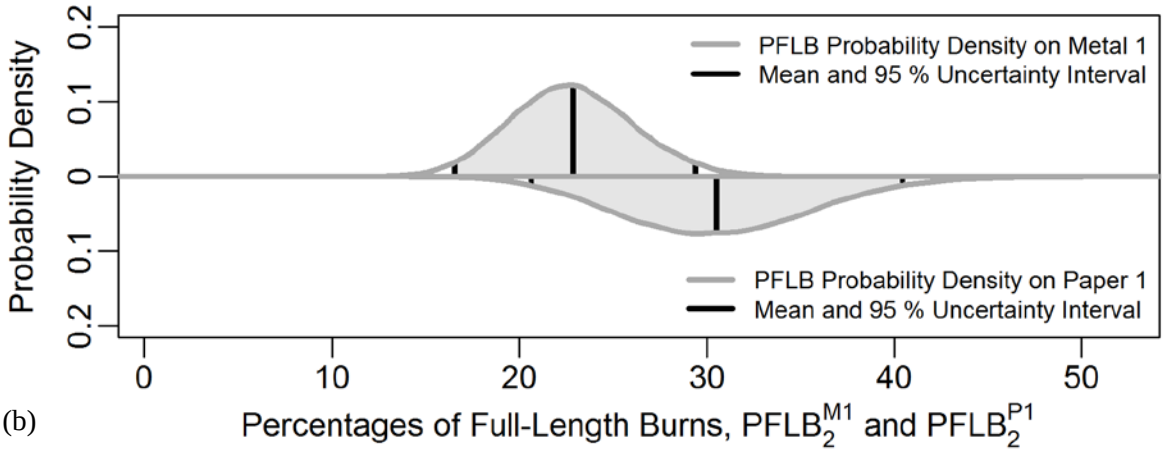

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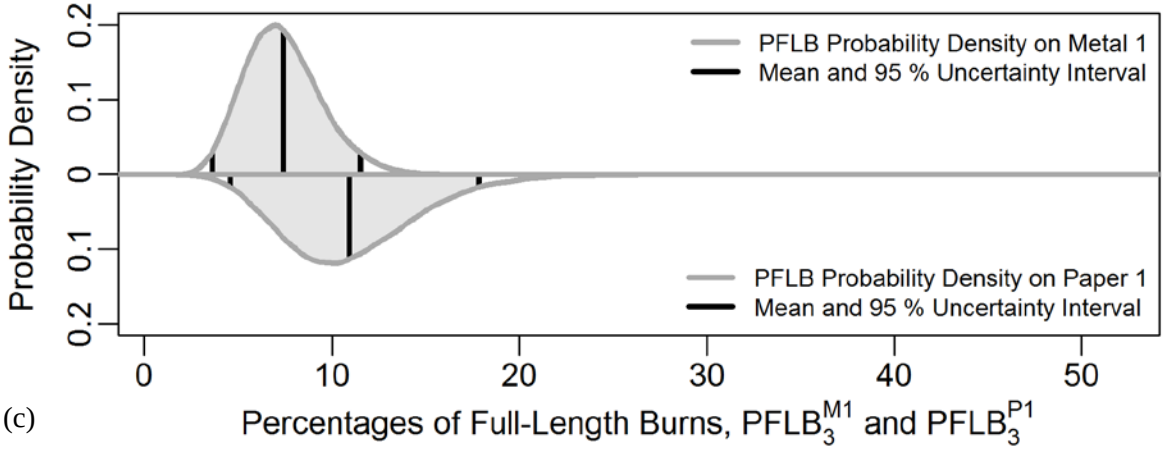

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A summary of the mean PFLB values for three types of shim stock and a single layer of Whatman No. 2, rough side up, is presented in Table 2. The 95 % expanded uncertainty intervals for all three metals overlap for all three of the cigarette designs. This suggests that the test performance of cigarettes is not likely to be strongly dependent on the source of the 302 stainless steel shim stock.

Table 2 Summary of mean PFLB values and uncertainties (calculated at the 95 % probability level) for the standard 10 layers of paper and each of the three shim stocks with a single layer of paper.

	PFLB Values			
Cigarette Design	**Paper ***	**Metal 1 §**	**Metal 2 §**	**Metal 3 §**
1	14.6 ± 7.6	13.6 ± 5.3	15.4 ± 5.8	16.1 ± 5.8
2	30.5 ± 9.9	22.9 ± 6.5	27.8 ± 6.9	20.4 ± 6.2
3	10.9 ± 6.9	7.4 ± 4.1	5.6 ± 3.6	4.9 ± 3.4

Table 2 Notes:

* Values calculated from 4 sets of 20 tests. Substrate: 10 layers of Whatman No. 2, rough side up.

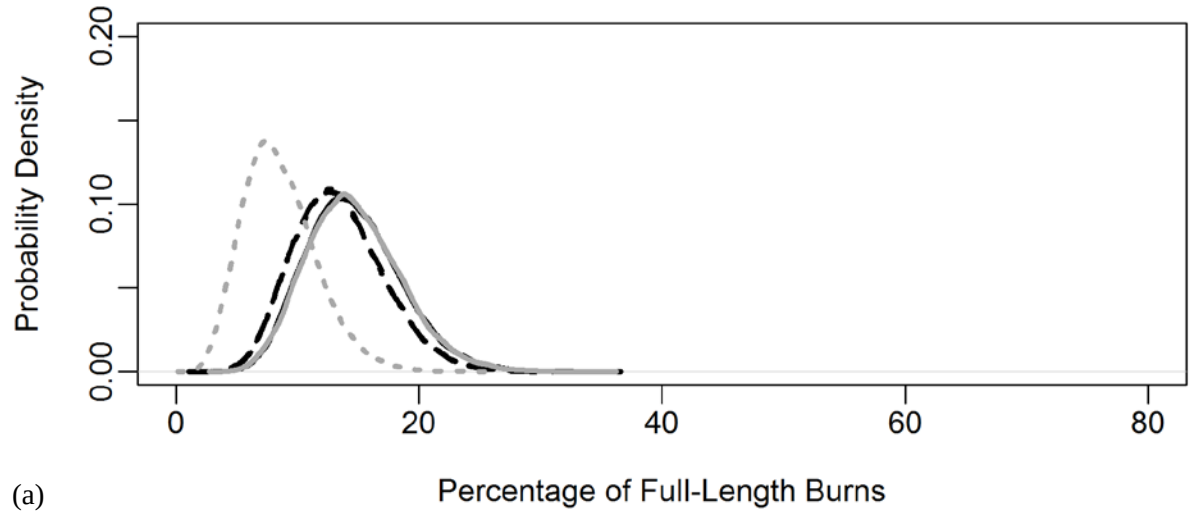
§ Values calculated from 8 sets of 20 tests. Substrate:1 layer of Whatman No. 2, rough side up on shim stock.

A graphical summary of results for five types/orientations of paper (described in Table 3) on Metal 2 and for three cigarette designs is shown in Figure 5. There is considerable overlap of the PFLB distributions for all five types/orientations of paper for each of the three cigarette designs. Further testing with multiple batches of the brands of filter paper will be needed to determine the extent to which a specification for the properties of the filter paper is needed.

Table 3 Descriptions of the five combinations used to test various papers on an example of the 0.2 mm 302 stainless steel shims considered.

Substrate Number	**Description of Single Sheet of Paper**	**Side Up**
1	Whatman No. 2 paper manufactured in the original location	Rough
2	Whatman No. 2 paper manufactured in the new location	Rough
3	Paper M	Rough
4	Paper N	Rough
5	Whatman No. 2 paper manufactured in the UK	Smooth

Figure 5 Summary of the PFLB distributions for each of the five substrates, using the papers described in Table 3, on Metal 2, for (a) Cigarette Design 1, (b) Cigarette Design 2, and (c) Cigarette Design 3.



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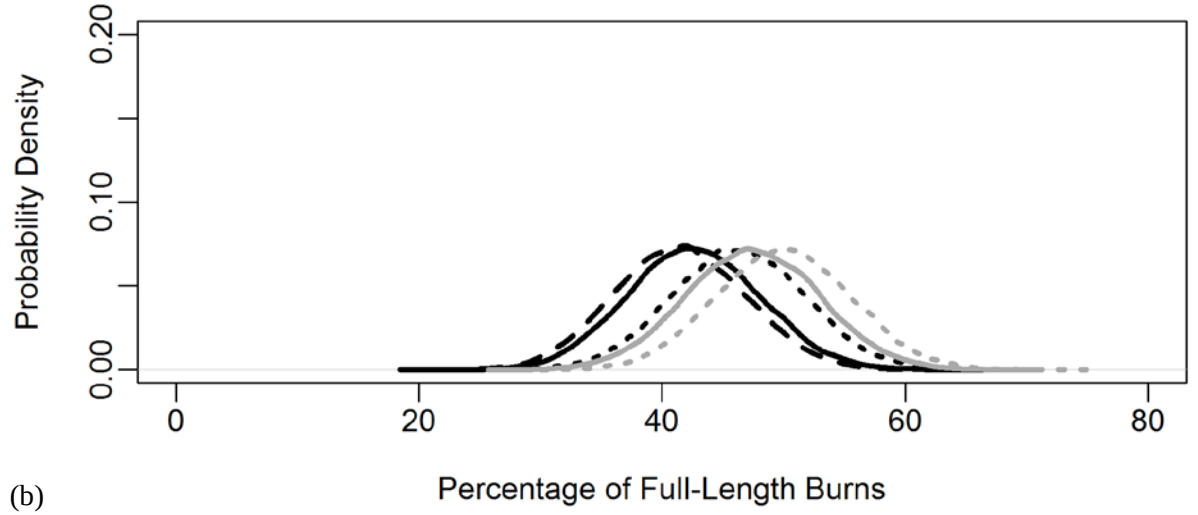

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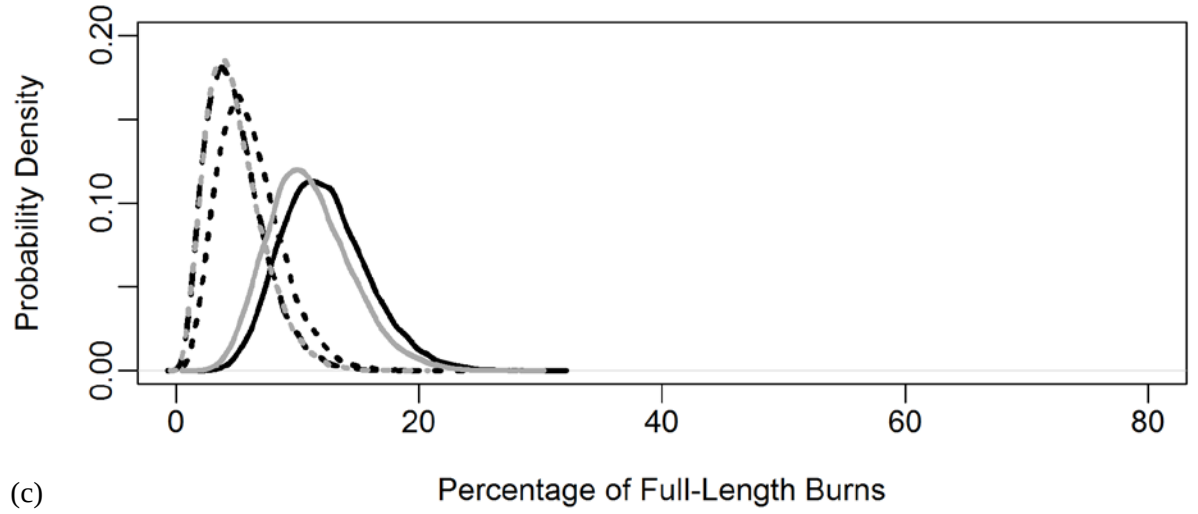

(c)

SUMMARY OF PRELIMINARY RESULTS

The alternate substrate of 0.2 mm thick 302 stainless steel with one layer of filter paper is promising. The PFLB results were statistically indistinguishable from those obtained using 10 layers of the Whatman No. 2 filter paper from the original manufacturing location for each of the combinations considered within this investigation (Table 2 and Figure 4).

- There was no significant dependence on the supplier of the steel shim stock (Table 2). However, shim stock may differ in thickness from batch to batch, and thermal diffusivity also affects the heat absorption. It is possible that a more complete specification for the shim stock, and possibly a Standard Reference Material, is needed.
- The tests results for the shim stock and one layer of filter paper (Figure 5) indicated little sensitivity to the manufacturers of the paper considered in this investigation.

There may be significant differences between the results for 10 layers of Whatman No. 2 paper made in the different plants for some cigarette designs (Figure 2). This provides further impetus for identification of an alternate substrate for ASTM E 2187 and the other standards based upon this (References 2 through 4).

An interlaboratory study of this alternate substrate is being planned under the auspices of ASTM and ISO. This will provide a larger data set involving more test operators, additional cigarette designs, and more batches of filter paper and steel shim stock.

ACKNOWLEDGEMENTS

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