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Small Flame Ignitability and Flammability Behavior of Upholstered Furniture Materials

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SMALL FLAME IGNITABILITY AND FLAMMABILITY BEHAVIOR OF UPHOLSTERED FURNITURE MATERIALS

John F. Krasny, Dingyi Huang[1]

Abstract

Identical upholstered furniture fabric and padding specimens were exposed to four increasingly severe small flaming ignition sources and to a radiant source. The small ignition sources were partly patterned after the Bunsen burner tests of BS 5852 Part 2. For the radiant source, the Cone Calorimeter was used, and specimens were exposed to irradiances of 10 and 15 kW/m^2. A wide range of ignition properties was found, depending on both the cover fabric and padding. The relationship between Cone Calorimeter and small scale ignition tests was generally as follows: Specimens, which, when exposed in the Cone Calorimeter at 15 kW/m^2 irradiance, reached a heat release rate of 50 kW/m^2 in less than 60 seconds generally were ignited by the two smaller sources used. Conversely, specimens which reached this heat release rate in longer times generally had greater small flame ignition resistance. Suggestions are also made for further improvements in the design of small scale flaming ignition and Cone Calorimeter tests for specimens combining a upholstery fabric and a padding. The major such improvement would be to break the char in such test, which probably often breaks in real life experiments but in small scale experiments may protect the padding material.

Key words: BS 5852 Part 2 test; Cone Calorimeter; ignition; heat release rate; mattresses; radiant ignition; upholstered furniture.

[1] Guest worker from the Shanghai Fire Research Institute, Peoples Republic of China.

1. Introduction

This paper describes a study of the small flame ignitability of upholstered furniture substrates[2] and its relationship to the behavior of the same materials under radiant heat exposure tests. Such a relationship, if available, could minimize the requirement for testing to be done with multiple test apparatuses or ignition sources.

The general topic of the burning behavior of upholstered furniture and mattresses (soft furnishings) has been discussed at length in a recent monograph [1]. Several major points are pertinent to the present study:

- Ideally, soft furnishings would resist ignition from three separate sources: cigarettes, small flames, and relatively high heat fluxes from burning items in a room. In the latter case, ignition cannot always be avoided, but low rates of flame spread, heat release, and toxic gases development are desirable.

- None of the most popular commercial cover fabrics and paddings used in soft furnishing have both cigarette and small flame ignition resistance [1]. For instance, cellulosic fabrics with cotton batting resist small flames somewhat better than thermoplastic fabrics over polyurethane foam. The latter combinations, however, have better cigarette ignition resistance.

- Cigarettes cause approximately 70 percent of the soft furnishing ignitions and over 30 percent of residential fire deaths [2,3]. Consequently, the United States has concentrated on protection against cigarette ignition. Mattresses are covered by a Federal standard administered by the Consumer Product Safety Commission (CPSC) [4]. A voluntary standard sponsored by the Upholstered Furniture Action

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[2] Substrate is here defined as an assembly consisting of a furniture or mattress cover fabric and padding.

Committee (UFAC) applies to residential upholstered furniture [5]. Another voluntary standard, by the Business and Institutional Furniture Manufacturers Association (BIFMA) applies to their furniture lines [6]. The National Fire Protection Association (NFPA) has adopted the UFAC standard under designation NFPA 260-A, and a standard developed by the National Bureau of Standards for the Consumer Products Safety Commission (but never adopted because of the UFAC voluntary action) as NFPA 260-B [7]. Also, furniture sold in California is covered by a state standard [8].

- Interest in small flame ignitability of soft furnishings in the United States has been relatively low. California [8] and BIFMA [5] have separate flame resistance tests for the fabric, padding, etc. California also has a mockup test for institutional furniture [9]. In this test, the specimen is a scaled down mockup of a chair containing fabric and padding arranged as in the proposed line of furniture. The ignition source is 9.5 g of crumpled newspaper. Several individual countries and the International Organization for Standardization (ISO) have adopted or are considering adoption of flame ignition tests for furniture, using a series of ignition sources of increasing intensity, based on the British BS 5852 Part 2 mockup test [10]. However, this test requires quite large specimens and, as written, does not give any fire hazard information beyond a pass/fail rating. No truly small-scale ignitability screening test for upholstered furniture specimens has been offered.

- Finally, an extensive discussion of the large amount of work on full scale fire behavior of soft furnishings is given in the above-mentioned NBS Monograph [1]. An analysis of many aspects of common, small ignition sources has been recently prepared by British researchers [11]. Correlation of large-scale behavior with bench-scale tests, especially the Cone Calorimeter, is discussed in [12]. Ignition of soft furnishings by other items which are burning in a room is analyzed in [13].

For this project, a small flame ignition screening test was developed. It is modeled loosely after the British BS 5852 Part 2 test, and uses four ignition modes of increasing severity. The Cone Calorimeter [14] was used to study the behavior of the same substrates under modest levels of irradiance, 10 and 15 kW/m^2. The Cone Calorimeter is typically used [1] to measure radiant ignitability, peak rates of heat release, and other fire characteristics related to the later stages of a fire. While direct flaming ignition data can always be obtained from running a set of tests in a BS 5852 Part 2 type apparatus, it was desired to explore whether, using the Cone Calorimeter alone, such measures could be evolved.

2. Materials

Six typical upholstery fabric and padding materials were chosen and are described in Table 1. Four fabrics (one thermoplastic, two cellulosics, and a wool) were each tested in conjunction with a polyurethane foam, a neoprene foam, and cotton batting paddings. In addition, two nylon fabrics (A and B) were tested with "combustion-modified" polyurethane foam specimens (F-4 and F-9). The latter substrates had been previously tested by the California Bureau of Home Furnishings using their newly-developed test method for institutional furniture in mockup form [9]. In some cases, single specimens of each substrate were exposed, in others, duplicates.

3. Methods

Sample Preparation.

For both the small flame ignition and Cone Calorimeter testing, the specimen size was nominally 100 x 100 mm, 50 mm thick. [The specimen size in the standard BS 5852 Part 2 procedure is substantially larger than that, which allows the use of crib ignition sources. Since cribs were not to be used in the present project, a smaller specimen size was adopted for this work.] The padding was covered with fabric cut into a cruciform shape. Both the top and the sides of the specimen were covered by fabric; the fabric was stapled to the padding near the bottom along the sides. For the Cone Calorimeter specimens, the sides of the specimen were covered with aluminum foil.

Ignition Tests.

The following small ignition sources were used in the small flame ignition tests:

Source 1 was a 150 mg methenamine pill, having a burning time of 90 to 120 s; this was placed in the center of the 100 x 100 mm, horizontal specimen surface. This pill has been reported to have similar ignition effects to the British Standard No. 1 ignition source [14], which, in turn, reportedly gives similar results to wooden matches [16-19].

The 100 x 100 mm surface of vertically-oriented specimens was also exposed to propane flames emanating from the British Standard burner, a 200 mm long, 6.8 mm ID stainless steel tube [10]. The lower edge of the flame was about 25 mm above the bottom edge of the specimen. Figure 1 shows the test arrangement. Three exposures were used in these vertical tests:

Source 2: 20s exposure time, 160 ml/min (97 W)
Source 3: 20s exposure time, 350 ml/min (210 W)
Source 4: 40s exposure time, 350 ml/min (420 W)

These sources do **not** correspond directly to the sources used by BS 5852 Part 2. Instead, they were chosen to cover a variation of both ignition time and ignition source severity. Testing was always started with source 1, the methenamine pill. When a substrate specimen ignited with one ignition source, this substrate was then generally exposed only to the next more severe ignition source, and only if sufficient material was available.

All specimens were tested while placed on a load cell platform, and mass loss vs. time graphs obtained. There usually was a "first slope" during the contact with the ignition source. Ignition would then be indicated by a sharp increase in this slope, and self-extinguishment by a decrease in the slope. (Self-extinguishment occurred on the specimen surface in some cases, in others only when the flames reached an edge. In such cases, larger specimens of the materials should be tested to determine whether self-extinguishment was due to an edge effect.) Specimens were extinguished after they lost 2 g because this mass loss occurred at or after the time when the specimens showed obvious flaming. Figures 2a and 2b show typical mass loss curves for these tests.

The Cone Calorimeter tests were carried out as prescribed in [14] and [15].

4. Results

The results of the Cone Calorimeter experiments, with 10 and 15 kW/m^2 irradiance distributed evenly over the specimen surface, and of the small ignition source experiments are shown in Table 2. Many specimens did not ignite at 10 kW/m^2 irradiance but only a few resisted 15 kW/m^2 irradiance. The peak heat release rate at each irradiance, the time it took to reach this rate, and the time to 50 kW/m^2 heat release rate are shown. In some cases, duplicate specimens were tested. The individual results differed by 10 to 70 percent of the average value shown in the table. (High scatter of results is normally seen in heat release rate tests for materials which are heated with an irradiance only slightly higher than their actual critical ignition flux.)

The following are the findings with respect to the behavior of the various materials shown in Table 2:

- With respect to fabric rankings:

  Substrates covered with wool fabrics had the highest resistance to the small ignition sources and to Cone Calorimeter exposures at 10 kW/m^2 irradiance, but ignited at 15 kW/m^2. Somewhat lower in ignition resistance were the various substrates covered with the heavy cotton fabrics, followed by those covered with the lighter cotton velvet. Finally, the olefin fabric covered substrates had the lowest ignition resistance, because the fabric shrank and melted, exposing the padding to the flames or irradiance. In some cases, the olefin-covered substrates performed worse than the padding alone; even some neoprene paddings ignited, probably because the molten olefin burned somewhat like a small pool fire.

- The two substrates containing the rather heavily bequeathed nylon fabrics A and B and the two proprietary combustion modified foams F-4 and F-9 resisted the 10 kW/m^2 exposure; the fabrics melted and the foams charred. At 15 kW/m^2, all but A/F-9 ignited readily. Exposed to the small flames, these substrates ignited, but in five of the eight experiments with ignition sources 1 and 2, self-extinguishment occurred. Insufficient material was available for tests with the other ignition sources. This self-extinguishing response is rarely seen under the irradiance of the Cone Calorimeter since the radiant heat source is not turned off during the test.

- With respect to the ranking of padding materials:

  As expected, the substrates containing neoprene had the best ignition resistance, with generally only the fabric burning if there was any ignition at all. The polyurethane-containing substrates ignited most readily.

- None of the padding materials tested without a fabric cover ignited upon small flame exposure except the polyurethane. (Cotton batting was not tested in the vertical mode because of specimen mounting difficulties.) The neoprene did not ignite in the Cone Calorimeter at either the 10 or 15 kW/m^2. The other materials, except for the F-9 foam, ignited at 10 kW/m^2.

Table 3 shows the same results but with the substrates arranged by increasing time to a 50 kW/m^2 rate of heat release, when tested in the Cone Calorimeter at a 15 kW/m^2 irradiance. Within the limitations imposed by the reproducibility of the results, the most important finding is that specimens which reached 50 kW/m^2 in a relatively short time, 60 s or less, also ignited with small flame ignition sources 1 or 2. Those with times exceeding 60 s generally did not sustain ignition with these ignition sources. Exceptions are specimens A/F4 and B/F4: in these cases, the nylon fabric melted and the moderately combustion modified foams burned tenuously when exposed to ignition source 2; the B/F4 combination ignited but self-extinguished under ignition source 1.

Thus a general relationship has been demonstrated between the ignition rankings in the burner tests and ones from the Cone Calorimeter data. There are a few discrepancies. Some of these may be explained by the finding that certain char-forming fabrics, in this case cotton and wool, can shrink and break open under conditions of uniform surface irradiance, as created in the Cone Calorimeter, while they may not do so when exposed to a small, localized test flame. When the fabric breaks open, ignition resistance becomes mostly a function of the padding characteristics. The wool and the heavy cotton fabric substrates were relatively easily ignitable in the Cone Calorimeter, compared to their better resistance to the small burner flame. Conversely, the specimens using the F-4 substrate ignited more readily from the small burner flame sources than their behavior in the Cone Calorimeter indicated. A specific reason for this behavior is not known.

5. Suggestions for Further Development of a Small Flame Ignitability Test Method for Upholstered Furniture Substrates.

This work was intended to be exploratory, to initiate development of a small flame ignition method for upholstered furniture, and the possible relationship of the results obtained by this method to Cone Calorimeter results.

The small flame ignition test arrangement used in this study appears to be basically viable for screening procedure specimens for resistance to ignition sources simulating matches, lighters, etc. However, if self-extinguishment is observed after the flame or smolder reach the edges of the flat area of the specimens, the test should be repeated with larger specimens to determine whether that the result was due to an edge effect. The mass loss vs. time curve can supplement visual observation of ignition or non-ignition, by direct indication of mass loss rates. Experiments with a wider variety of fabrics and padding materials should be conducted to confirm the above findings, and to determine mass loss vs. time slopes which correspond to continuous flaming, smoldering, and self-extinguishment behaviors.

The results also indicate that measurements available from the Cone Calorimeter may also be used to predict whether or not small flame ignitions may occur. Specimens which, under 15 kW/m^2 irradiance require more than 60 seconds to reach 50 kW/m^2 heat release rate will probably not be ignited by exposure to burning matches or cigarette lighters. By such a use of the data from the Cone Calorimeter (which has additional applications to furniture flammability testing [12]), possibly separate flaming ignition testing and test apparatus can be obviated. A larger number of replicate tests should be run and confidence limits established.

Two factors limit the quality of this prediction. First, some char- forming fabrics shrink and break in the Cone Calorimeter, but not upon exposure to small ignition sources. Second, there might be an irradiance threshold for the release of gas phase flame retardant which may not be attained with small ignition sources. In both cases, the Cone Calorimeter results are closer to the worst case than are the small flame ignition sources. Further exploration of the effects of the two larger ignition sources discussed here, and possibly additional ignition sources, seems indicated.

The work then suggests a test method modification. In future work, consideration should be given to the fact that char-forming fabrics only protect the padding until they break open. Breaking open can occur due to the tension applied to the upholstery fabric during furniture manufacture and can be exacerbated by heat shrinkage, or due to char brittleness. Breaking open may also depend on both the size of the specimen and the size of the area exposed to flames or radiant heat, and may be less likely for the small-size specimens used in the small-flame ignitability apparatus or even the Cone Calorimeter, than for full-scale furniture. It could, however, be simulated by piercing the fabric some time during exposure, to simulate (quite likely to occur) worst case conditions.

The relationships identified in this paper, when developed and implemented for testing use, could result in savings of test effort, since the Cone Calorimeter could be used to predict the behavior of upholstery materials both towards small ignition sources as well as in larger fires.

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Table 1. Materials

Designation	Materials	Weight	Description
A. Fabrics		**(g/m^2)**	
OL	Olefin	360	dyed, bequeathed
CV	Cotton	560	dyed, velvet
HC	Cotton	650	raw cotton, bequeathed
W	Wool	480	dyed, bequeathed
A	Nylon	450	dyed, bequeathed
B	Nylon	285	dyed
B. Padding		**(kg/m^3)**	
PU	Polyurethane foam	17	
NP	Neoprene (Toyad LS 200)[a] foam	142	
CB	Cotton batting	27	not flame retarded
F4	Experimental foam	45	
F9	Pyrothane CMHR (Scott Co.)[a] foam	76	Combustion modified, high resiliency polyurethane

NOTE: All materials except padding F4 are commercially available.

[a] Certain commercial materials are identified in this paper in order to illustrate adequately certain specific characteristics. Such identification does not imply recommendation or indorsement by the National Bureau of Standards, nor does it imply that the item is necessarily the best available for the purpose.

Table 2. Ignition Behavior of Upholstered Furniture Substrates
(arranged by material)

Fabric	Padding	Cone Calorimeter, Irradiance 10 kW/m² Peak RHR (kW)	10 kW/m² Time to Peak (s)	10 kW/m² Time to 50 kW/m² (s)	15 kW/m² Peak RHR (kW)	15 kW/m² Time to Peak (s)	15 kW/m² Time to 50 kW/m² (s)	Small Ignition Source Ignition Behavior (two replicates) 1*	2*	3*	4*
W	NP	N	-	-	115+	110+	100+	N/N	N/N	N/N	SE/N
	CB	N	-	-	275	90	75	N/N	N/N	N/N	SE/SE
	PU	N	-	-	330+	195	105+	N/N	N/N	I/I	I/I
CV	NP	N	-	-	165	210	195	N/N	N/N	N/N	I/N
	CB	190	150	135	265	65	50	SE/SE	I/I	-	-
	PU	215	285	180	235	195	55	I/I	I/I	-	-
HC	NP	125	215	205	165	115	105	N/N	SE/N	SE/N	-
	CB	160	135	120	205	100	85	N/N	SE/SE	SE/SE	SE/SE
	PU	170	140	125	195	95	80	N/N	SE/SE	IS/IS	-
OL	NP	135	160	140	220	45	35	I/N	I/N	-	-
	CB	210	90	80	365	30	15	I/I	I/I	-	-
	PU	375	170	80	420	110	20	I/I	I/I	-	-
A	F-9	N	-	-	N	-	-	SE/SE	SE/SE	-	-
	F-4	N	-	-	200	330	115	SE/N	I/I	-	-
B	F-9	N	-	-	280	170	155	SE/SE	SE/SE	-	-
	F-4	N	-	-	230	190	120	IS/IS	I/I	-	-
none	NP	N	-	-	N	-	-	N	N	N	N
	CB	90	170	165	-	-	-	-	-	-	-
	PU	415	130	80	335	75	20	I	I	I	I
	F-9	N	-	-	95	75	70	N	N	N	N
	F-4	95	790	530	155	95	65	N	N	N	SE

+: Heat release rate of one specimen; duplicate did not ignite.
*: 1 - Methenamine pill, 150 mg, horizontal orientation
2 - 160 ml/min butane for 20s, vertical orientation
3 - 350 ml/min butane for 20s, vertical orientation
4 - 350 ml/min butane for 40s, vertical orientation
N: No ignition
I: Ignition
SE: Ignition but self-extinguished
IS: Ignition--smoldered

Note: Repeatability for peak heat release rate measured by the Cone Calorimeter is generally within 10 percent: it is higher, up to perhaps 20 percent for time to events. However, some of the specimens of the present series ignited, while duplicates did not ignite, depending on whether the cover fabric broke open and exposed the padding.

Table 3. Ignition Behavior of Upholstered Furniture Substrates[a]

Specimen	Time to ignition (10 kW/m^2)	Time to ignition (15 kW/m^2)	Time to 50 kW/m^2 (15 kW/m^2)	Peak heat release rate (15 kW/m^2)	Small ignition sources #1	#2	#3	#4
OL/CB	70	25	15	365	I/I	I/I		
OL/PU	85	30	20	420	I/I	I/I		
OL/NP	140	45	35	220	I/N	I/N		
CV/CB	125	55	50	265	SE/SE	I/I		
CV/PU	140	60	55	235	I/I	I/I		
W/CB	∞	50	75	275	N/N	N/N	N/N	SE/SE
HC/PU	115	65	80	195	N/N	SE/SE	IS/IS	
HC/CB	110	65	85	205	N/N	SE/SE	SE/SE	SE/SE
W/NP	∞	100	100	115	N/N	N/N	N/N	SE/N
HC/NP	195	125	105	165	N/N	SE/N	SE/N	
W/PU	∞	85	105	330	N/N	N/N	I/I	I/I
A/F4	∞	95	115	200	SE/N	I/I		
B/F4	∞	100	120	230	IS/IS	I/I		
B/F9	∞	140	155	280	SE/SE	SE/SE		
CV/NP	∞	170	195	165	N/N	N/N	N/N	I/N
A/F9	∞	∞	∞	0	SE/SE	SE/SE		

a: arranged according to time to reach 50 kW/m^2, with an imposed irradiance of 15 kW/m^2.
*: 1 - Methenamine pill, 150 mg, horizontal orientation
2 - 160 ml/min butane for 20s, vertical orientation
3 - 350 ml/min butane for 20s, vertical orientation
4 - 350 ml/min butane for 40s, vertical orientation
N: No ignition
I: Ignition
SE: Ignition but self-extinguished
IS: Ignition--smoldered

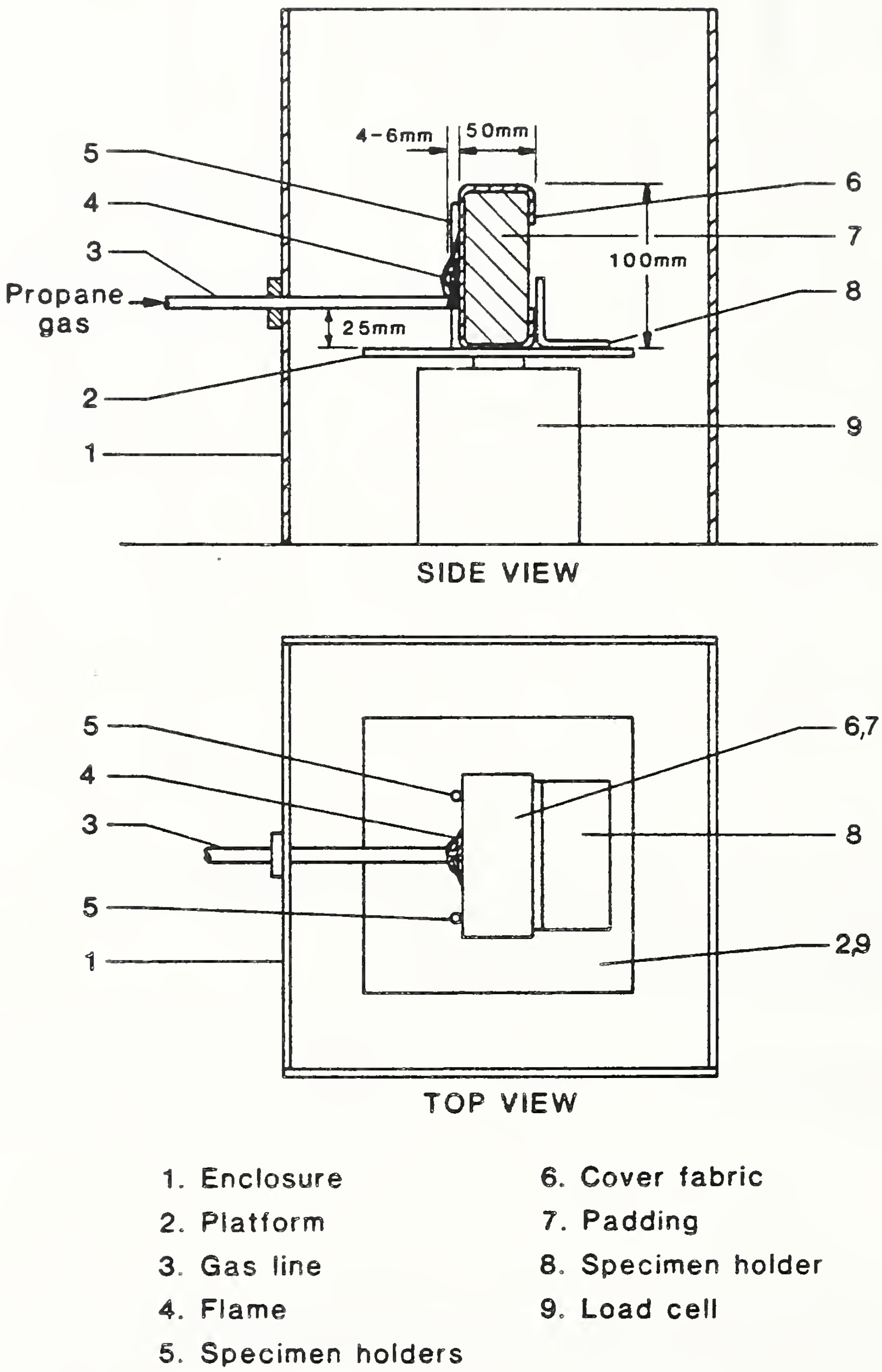

Figure 1. Small flame test arrangement

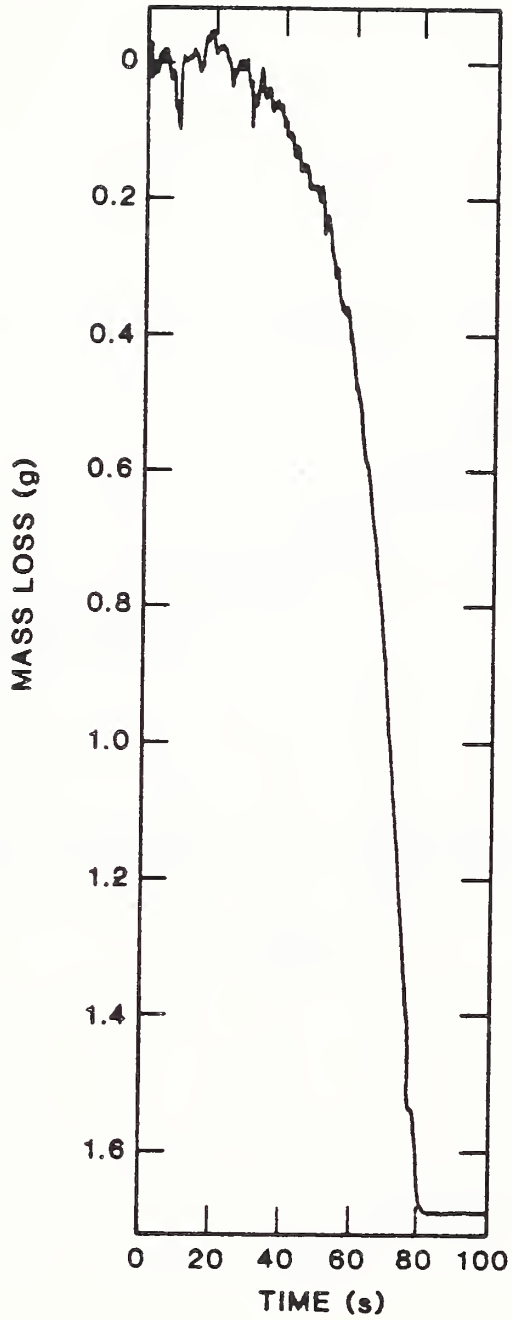

Figure 2A. Example of specimen showing ignition when exposed to a small flame test

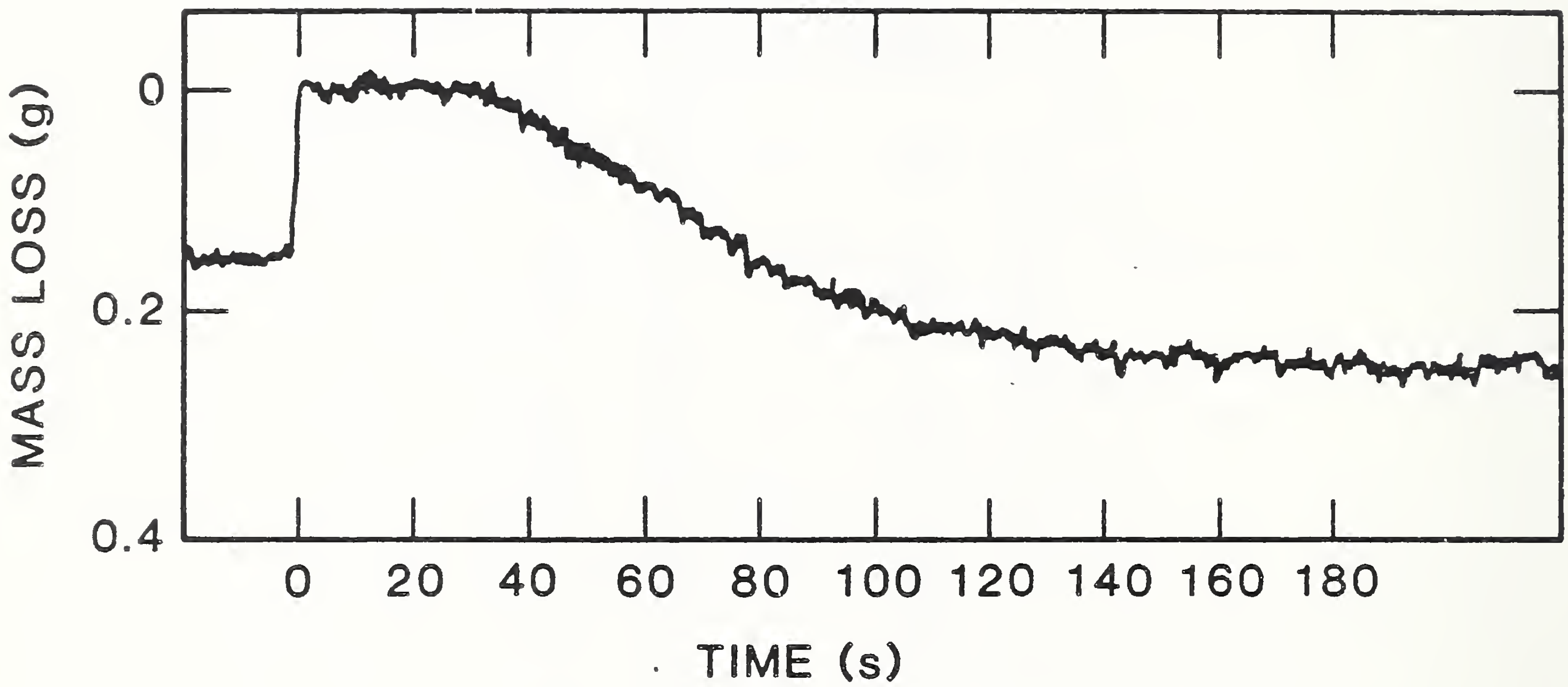

Figure 2B. Example of specimen not showing ignition when exposed to a small flame test

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Identical upholstered furniture fabric and padding specimens were exposed to four increasingly severe small flaming ignition sources and to a radiant source. The small ignition sources were partly patterned after the Bunsen burner tests of BS 5852 Part 2. For the radiant source, the Cone Calorimeter was used, and specimens were exposed to irradiances of 10 and 15 kW/m^2. A wide range of ignition properties was found, depending on both the cover fabric and padding. The relationship between Cone Calorimeter and small scale ignition tests was generally as follows: Specimens, which, when exposed in the Cone Calorimeter at 15 kW/m^2 irradiance, reached a heat release rate of 50 kW/m^2 in less than 60 seconds generally were ignited by the two smaller sources used. Conversely, specimens which reached this heat release rate in longer times generally had greater small flame ignition resistance. Suggestions are also made for further improvements in the design of small scale flaming ignition and Cone Calorimeter tests for specimens combining a upholstery fabric and a padding. The major such improvement would be to break the char in such test, which probably often breaks in real life experiments but in small scale experiments may protect the padding material.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

BS 852 Part 2; cone calorimeters; heat release rate; ignition; mattresses; radiant ignition; upholstered furniture

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