

## Upholstered Furniture Transition from Smoldering to Flaming

**REFERENCE:** Babrauskas V, Krasny JF. Upholstered furniture transition from smoldering to flaming. *J Forensic Sci* 1997; 42(6):1029-1031.

**ABSTRACT:** This paper reviews the available literature on experimental measurements of smoldering to flaming transition in upholstered furniture. It is found that of 102 items, 64% made the transition to flaming. For the items which transitioned to flaming, the time for the transition to occur ranged from 22 to 306 min. Some of the factors affecting the likely time to transition are known qualitatively, but a quantitative method of prediction is not available which would allow one to predict such transition occurrence (and time) on the basis of construction details and fire environment.

**KEYWORDS:** cigarettes, forensic science, chairs, fire tests, mattresses, smoldering, upholstered furniture

Upholstered furniture can burn either by smoldering or by flaming. A flaming fire is one which exhibits visible flames. Smoldering, by contrast, is a slow, low-temperature, flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed-phase fuel (1). A smoldering fire is most commonly caused by a carelessly discarded cigarette, although electrical and other causes are also found. Once an article starts smoldering, however, the exact cause of smoldering is considered immaterial to its further development. When a furniture item smolders, the toxicity of the combustion products may be high. The amount of mass being lost, however, is very small. Thus, deaths in the case of smoldering fires tend to occur only either to a person directly involved with the fire, or after a long time of smoldering has elapsed (for rooms away from the fire origin). A flaming fire can occur if a furniture item is directly ignited with a flame, for example, a cigarette lighter. Flaming fires can be extremely rapid. It is not unusual for a chair to reach its peak heat release rate in some 3 min and be nearly gone in 8 or 10 min (2,3).

For there to be a flaming furniture fire, it is not necessary to ignite the object with a flame. Many furniture items start by smoldering, but at some time later erupt into flaming combustion. Thus, the time scale for fire hazard development can depend crucially on the transition time from smoldering to flaming. This time of transition can be important in court proceedings.

Prosecutors in criminal cases have occasionally based their cases on the assumption that it takes several hours from a cigarette-induced ignition in an upholstered item to the occurrence of a

flame. In one case a fire was claimed to have been started within a particular time frame by an accidentally, and unnoticed, dropped cigarette. The fire department was called to put out a flaming fire in a shorter period of time than believed possible by the prosecution. The subject was found guilty of arson and sentenced to a long prison sentence. When data were made available indicating that shorter times for transition to flaming had actually been observed in other cases, this case was reversed on appeal.

### Items Prone to Smolder

Most conventional upholstered furniture is readily ignitable by flaming sources.<sup>3</sup> Not all furniture items can show smoldering. In fact, with modern furniture, the fraction of items capable of smoldering is much less than with traditional construction types, although hazards under flaming conditions are often greater. The materials most prone to smoldering are cotton fabrics, cotton batting paddings, and latex foam paddings. Polyurethane foam paddings generally are much more highly resistant to smoldering, however, some do smolder. Cotton batting is no longer a dominant form of upholstered chair construction, although it still sees some application for mattresses. Cotton batting can be made to resist smoldering by application of suitable chemical treatments, typically boric acid crystals. A Federal regulation intended to prohibit smolder-prone mattresses from being manufactured has been in place since 1972 (4). The existence of the regulation, of course, does not entirely preclude smolder-prone mattresses from entering the marketplace. Furthermore, many mattresses of earlier manufacture are still in use.

For other upholstered items, chairs, sofas, hassocks, etc., no mandatory Federal regulation exists controlling smoldering behavior. The US Consumer Product Safety Commission decided in the early 1980s not to adopt a regulation, but instead to rely on a voluntary industry program, called UFAC (Upholstered Furniture Action Council), for minimizing smoldering tendencies of seating items. Not all manufacturers participate in this program. Furthermore, CPSC has occasionally tested furniture labeled as conforming to the UFAC standards and found that typically only around 70% of the furniture labeled as conforming to UFAC standards for smolder resistance actually do resist cigarette ignition (5).

Thus, mattresses newer than the early 1970s are likely to be resistant to smoldering. Upholstered seating products made since the early 1980s are also likely to be smolder-resistant. However, since the voluntary standard for seating furniture is much less adhered to than the mandatory standard for mattresses, even new upholstered seating is less likely to be smolder-resistant than are mattresses.

<sup>3</sup>Some fabric/foam composites can resist ignition from very small flames. However, few chairs on the market can resist ignition from larger flames, for instance, flames from a burning throw pillow or jacket.

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It must be pointed out that there is no correlation between resistance to smoldering and good fire performance under flaming fire conditions. For example, upholstery systems involving polyurethane foam padding and medium-to-heavy weight thermoplastic (polyolefin, polyester, nylon) fabrics are normally resistant to smoldering, but often show very poor performance under flaming fire conditions.

### Theory of Smoldering

A theory exists for smoldering combustion. Much of the work was done by T. J. Ohlemiller, first at Princeton University and subsequently at the National Institute of Standards and Technology (NIST). Ohlemiller's studies are summarized in the SFPE Handbook (1). The theory indicates the importance of porous item density, air flow rate and direction, etc. At the present time, however, the theory cannot be used to predict whether an upholstered furniture item will smolder or not. Ohlemiller also summarized the fundamental combustion studies pertinent to the transition to flaming. Here, predictability was equally impossible and the theoretical basis was even sketchier.

### Survey of Literature

Given the state of non-predictability of the smoldering-to-flaming transition according to theory, it becomes important to examine experimental data on the subject. Seven well-documented test series were found to have been described in the literature where more than one or two items were systematically studied.

The California Bureau of Home Furnishings (BHF) placed cigarettes on 15 commercial chairs (6). Five self-extinguished after prolonged periods; one smoldered until it was extinguished after 330 min; and nine eventually went into flaming. Because these were commercial furniture items varying greatly in shape as well as materials, little could be learned about construction factors which resulted in flaming except, perhaps, that the presence of thermoplastic fibers seemed to reduce the tendency for transition to flaming.

Similar results regarding the transition to flaming were found in a few experiments with cigarette ignited chairs containing thermoplastic batting in the seats (7). When polyester batting was the padding material, the probability of transition to flaming was decreased as compared to polyurethane and cotton batting. However, the rate of glowing (for those fabrics which did glow) seemed to be increased when polyester batting was substituted for polyurethane foam or cotton batting. The fastest transition from smoldering to flaming (22 min after placement of the cigarette) was in a chair in which a heavy cotton fabric covered the cotton batting; in chairs with lighter cellulosic fabrics and mostly polyurethane padding it was about one hour. A draft in the test room favored flaming.

In tests performed in abandoned housing in the Indiana Dunes in the late 1970s, an assortment of commercially available new and second-hand furniture was ignited with a glowing heater element (8,9). The average times of smoldering before flaming were 70 min for the chairs and sofas and 85 min for the mattress/box spring assembly in the original test series.

Another test was later conducted at the U.S. National Bureau of Standards (NBS; since 1988 known as National Institute of Standards and Technology) under somewhat different conditions on replicate chairs and resulted in flaming after an average of 44 min (10). The chairs were covered with a cotton upholstery fabric, and padded with either cotton batting or polyurethane foam. None of the components were fire retarded. It is interesting to note that

for this set of 12 identical chairs, the transition times varied from 29 to 63 min. This kind of variation emphasizes that all aspects of smoldering phenomena are highly statistically variable and that this variation must be considered before placing much reliance on mean values.

In 1970, Southwest Research Institute reported cigarette ignition test results on innerspring mattresses using cellulosic ticking (11). In some cases, where no smoldering ignition took place with one cigarette, two cigarettes were placed side by side; these results are thus pertinent for times from inception of smoldering to flaming but not for cigarette ignition resistance of the composites. These mattresses were tested without and with sheets or blankets containing various fibers; pillows were included in some test arrangements. A vinyl mattress cover underneath the sheet caused relatively slow transition to flaming.

Six chairs with cover fabrics made from various fibers were also tested. A chair covered with polypropylene fabric flamed in 22 min (it may have been a rather thin fabric; medium or heavy weight thermoplastic fabrics generally have relatively good cigarette ignition resistance. However, this was one instance where two cigarettes side by side were used). Foam rubber (latex) seemed to transit into flaming relatively early.

The above data are tabulated and summarized in Table 1.

### Conclusions

Out of a total of 102 items subjected to smoldering ignition in laboratory tests, 32% burned up partially or completely without erupting in flaming; 64% did go to flaming, while the remainder were manually extinguished or were indeterminate (Table 1). For the chairs which did not go to flaming, the time for the chair to be essentially consumed can be long; one study reported an experiment where smoldering persisted for over 6 hours.

The mean smoldering-to-flaming transition observed in the laboratory tests was 88 min, the minimum 22 min, and the maximum 306 min. The conclusion can be drawn that transition times in the range 22 to 306 min are possible, but NOT that transitions outside of this range are impossible. The maximum and the minimum values found in a given sample of a population will depend not only on the traits of the population but on the sample size. Thus, if more than 102 fires of smoldering origin were examined, it is likely that values outside the given range would have been found. There are physical limits to this, however. Times in the range of seconds would be impossible, since smoldering is not established before some minutes have elapsed. Conversely, an item cannot transition to flaming if it has been smoldering long enough to be essentially consumed.

The data for mattresses in Table 1 would suggest that the minimum transition time for mattresses is longer than that for chairs. This is probably not a statistically justified conclusion, however, due to differences in experimental details and due to the modest size of the samples. It is more prudent to lump all of the experimental data into one population and to consider only times pertinent to "upholstered items" in general. Drafty room conditions can bring on the transition earlier than still air, but this effect has not been quantified.

The existing data do not permit firm conclusions regarding the fabric and padding materials which are most prone to transit to flaming. However, qualitatively it might be expected that materials having lower cigarette ignition resistance might also be more likely to transit to flaming.

TABLE 1—*Experimental data on smoldering-to-flaming transition.*

Series Ref.	Type of Item	Number of Items				Time to Flaming (min)	
		Total	Burned up or went out without flaming	Went to flaming	Other†	Avg.	Range
(6)	Commercial chairs	15	5	9	1	142	60–306
(7)	NBS experimental chairs	6	3	3	0	48	22–65
(8,9)*	Sofas and chairs	24	7	17	0	72	28–132
(8,9)*	Mattresses and box springs	18	8	10	0	85	51–129
(10)*	Chairs	22	10	12	0	44	29–63
(11)	Solid foam and innerspring mattresses	11	0	8	3	140	97–233
(11)	Chairs	6	0	6	0	97	22–152
Totals		102	33	65	4	88	22–306

\*Electric ignition source; the remaining test series used cigarette ignition.

†Manually extinguished, or status unclear.

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