BURNING BEHAVIOUR OF UPHOLSTERED CHAIR: PART I

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(Received, October 18, 1983)

ABSTRACT

The burning tests of several wood cribs and several modern chairs with soft foam upholstery were carried out in a room. The mass burning rate, gas temperatures inside and outside the plume, smoke density, radiant heat flux, etc. were measured. The burning behaviour of the wood crib is very smooth whereas that of the modern upholstered chairs is not simple and depends on many factors. However, according to the experiments conducted in this study, it seems reasonable to assume that the mass burning rate after the peak burning rate is proportional to residual weight, so the mass burning rate, $\dot{m}$, for this burning period can be estimated with the equation, $\dot{m} = rAw_0 \exp(-A(t-T_p))$. The three parameters, T_p , r , and A , in this formula are determined on the basis of ranked burning rate. In the case of chairs, grouping the type of chair according to ranked burning rate allows one to determine these parameters for each group.

1. INTRODUCTION

Recently, the ignitability and fire behaviour of modern upholstered furniture has become an important issue. The soft foams used in modern upholstery are easily ignited and produce fires which are relatively intense, usually of short duration, and accompanied by large amounts of smoke. During the pre-flash-over period of a room fire the burning behaviour of the room is affected strongly by such furniture. Therefore, it is important that the overall fire behaviour of modern upholstered furniture is investigated.

The purpose of this study is to analyse the behaviour and the potential hazard of burning

furniture in a room. The main items of furniture which will be considered in the present work are upholstered chairs and settees. In this paper, the burning rate will be investigated in detail.

2. EXPERIMENTAL

The full-scale tests were carried out in the test room shown in Fig. 1. The room has a volume of about 175m^3 , floor dimensions of approximately 6m by 6m, height of 4.85m, and one doorway opening of 0.9 m width by 1.0m height. The test room is constructed of reinforced concrete panels.

Fig. 1 Test Room and Measurement Items

The test specimens consisted of 9 upholstered chairs, 4 upholstered settees, several wood cribs. All furniture was secondhand, and the upholstered chairs and settees were modern furniture. The ignition source for upholstered items was either two solid methanamine pills or a solid methanamine tablet setting on the seat. For the wood crib it was soft-tex soaked with 100cc methanol located beneath the crib.

The test specimen was located on the load platform in the center of the room. The measurement items were the weight loss, the gas temperatures inside plume, a vertical gas temperature profile and smoke density distribution inside the test room, the radiant heat flux from the flame, and the height of the flame.

3. THE EXPERIMENTAL RESULTS

3-1 Mass burning rate

The mass burning rate and the residual weight ratio of the wood crib are shown in Fig. 2-1. The curve of residual weight ratio is very smooth, and the mass burning rate reveals a peak at a few minutes after ignition and gradually decreases after the peak. On the contrary, the burning behaviour of an upholstered chair is very irregular. In all cases the fire-buildup on the furniture item happens suddenly after gradual burning. In some cases (e.g. Fig. 2-2) the burning has no extreme peak, while in others (e.g. Fig. 2-3) there is an extreme peak.

The modern upholstered furniture items used in the present tests produced substantial residual weights due to unburnt parts such as

the wood frame (see Fig. 2-2 and 2-3). The foam materials in these items burn in the active burning period. In any event, it is clear that the burning behaviour of a piece of furniture

depends on its configuration and component materials and this behaviour is not always adequately simulated with a burning crib.

Fig. 2-1 Burning Rate and Residual Weight of Wood Crib

Fig. 2-2 Mass Burning Rate and Residual Weight of Chair

Fig. 2-3 Mass Burning Rate and Residual Weight of Chair

3-2 Smoke generation

By considering a test room space as a series of horizontal stories, measuring $Cs(i)$, the smoke density in story i , and multiplying by $V(i)$, the volume of story i , the total smoke release can be calculated with the equation,

$$Cs \cdot V = \sum Cs(i) \cdot V(i).$$

Fig. 3 shows the relationship between $Cs \cdot V$ and W , the burning weight loss. The smoke generation coefficient, K , is defined as the slope of the $Cs \cdot V$ vs W curve. In many cases, this curve cannot be adequately approximated with a single straight line, thereby indicating a non-uniform K . The results in Fig. 3 as well as other results indicate that three distinct phases or slopes appear in many cases. As it is assumed that the mass burning rate also has three distinct phases (the first phase is before fire buildup, the second phase is the high mass burning rate period after fire buildup, and the third phase is after burning down), the propensities of the smoke generation and burning rate

phases are expected to correspond with each other (Fig. 3). The value of K for an upholstered chair has been found to be large than that for a wood crib. Therefore, the smoke produced by the upholstered chair is greater than that produced by the wooden items.

Fig. 3 Smoke Generation

3-3 Radiant heat flux

A single point target irradiance measurement was provided. This was made with a radiometer (Tokyo Seiki, RE-3) facing the fire 3.0m in front of the specimen and at a height of 1.0m above the floor. The fluxes are given in Fig. 4 as a function of peak mass burning

rate. It is clear that as a first approximation the radiant heat flux can be considered a linear function of peak mass burning rate. Although not present here the curves of the flame height vs time, the mass burning rate vs time, and radiant flux vs time have similar shapes to each other.

Fig. 4 Radiant Heat Flux at Peak

4. DISCUSSION

The discussion which follows will be directed at establishing burning rate models for the crib and upholstered furniture tested in this study.

4-1 Wood crib

Fig. 5 shows the relationship between mass burning rate and residual weight of the wood crib. After the peak of the mass burning rate the burning rate decreases with the decrease of weight. This suggests that after fire buildup

the mass burning rate $\dot{m}$ is proportional to residual weight; that is,

$$\dot{m} = -dw/dt = Aw$$

where $\dot{m}$ is the mass burning rate,

w is the residual weight, and

A is the burning coefficient.

Fig. 5 Residual Weight vs Mass Burning Rate

Let T_p denote the time to reach the peak mass burning rate and r denote the ratio of residual weight at the peak to the initial weight, w_0 , then integration of equation (1) gives

$$w/w_0 = \exp(-A(t-T_p)) \quad (t > T_p) \quad (2)$$

The left hand side term of equation (2) is the residual weight ratio, RW. Equation (2) reveals that RW decreases exponentially with elapsed time, t . Substituting equation (2) into equation (1) gives

$$\dot{m} = Arw_0 \exp(-A(t-T_p)) \quad (t > T_p) \quad (3)$$

Equation (2) and (3) include three characteristic burning parameters, r , A and T_p .

T_p and r are associated with the peak of burning and A is the parameter which provides the burning intensity after the peak. These parameters can be obtained from the experimental results. In the case of the wood crib in the present work

$$r = 0.87, A = 0.00257, \text{ and } T_p = 120.$$

Therefore equation (3) becomes

$$\dot{m} = 0.00224 w_0 \exp(-0.00257(t-120)) \quad (120 < t).$$

Fig. 6 shows the actual and estimated mass burning rates and residual weight ratios. Between $t = 0$ and $t = T_p$ the mass burning rate can be approximated with the proper arbitrarily defined equation. In this case, it was empirically approximated with the straight line.

Fig. 6 Burning Rate of Crib (actual and estimated)

As a result, this model shows promise in effectively describing the mass burning rate of wood cribs. However, since the parameters r , A and T_p depend on several factors, it may be too easy to determine them with only a few results. Therefore more systematic experiments will be needed in order to determine them.

4-2 Urethane foam slab

The modern upholstered furniture used in this study contains so much soft urethane foam that it is easily ignited and quickly burns. The burning behavior of urethane foam was reported by Mizuno et al⁽¹⁾. The results of Ref. (1) show that the residual weight curves of urethane foam are very smooth like those of a wood crib. Consequently it should be possible to estimate the mass burning rate of urethane foam using the same method used for the wood crib. In the case of the urethane foam reported in Ref. 1,

$$r = 0.60, T_p = 120, \text{ and } A = 0.02.$$

Therefore, equation (3) becomes

$$\dot{m} = 0.0012 w_0 \exp(-0.02(t-120)) \quad (120 < t).$$

Fig. 7 shows both the estimated and actual mass burning rates of a urethane foam slab.

Fig. 7 Burning Rate of Urethane Foam (actual and estimated)

4-3 Upholstered chair

Since foam and fabric generally burn first and at high burning rate and the burning of wood frame is very slow and at low level, tests were stopped and data gathering discontinued when the majority of foam and fabric became very small.

The residual weight ratios of upholstered furniture when tests were stopped are shown in Table 1. These ratios depend on the framing components and indeed the residual weights are nearly equal to the weights of frames. These ratios exhibit scatter, but a mean value should be adequate for modeling purposes.

Table 1. T_p , r and A

Test item	Test No.	RW (end) %	T_p min:sec	r x 1/100	A 1/sec	Cover
Chair	1	55	11:30	75	0.00464	c
	2	53	12:00	65	0.00473	c
	3	57	20:15	80	0.00597	c
	4	62	6:00	60	0.01320	sl
	5	66	n.p.	—	0.00501	sl
	6	69	n.p.	—	0.00522	sl
	7	85	13:00	75	0.00545	c
	8	77	7:30	40	0.01040	c
Settee	9	69	23:15	70	0.00783	c
	10	66	18:30	65	0.00533	c
	11	75	2:15	75	0.00696	nc-sl
	12	61	16:00	71	0.00163	sl
	13	59	9:45	60	0.00482	sl

c : cloth, sl: synthetic leather
nc: partly non-cover
np: no substantial peak

In the case of a chair, by defining the modified initial weight, w_0^* , as the total burning weight in test time and the modified residual weight ratio, RW^* , as $(w - (w_0 - w_0^*)) / w_0^*$, and adopting RW^* instead of RW , it is possible to approximate the mass burning rate and the residual weight with the method used for the wood crib. RW^* values for upholstered chair are given in Fig. 8. The values of r , T_p and A determined from these experimental results as shown in Table 1. It is clear that there is a difference in burning behaviour between urethane foam slabs and upholstered chair.

Fig. 8 Modified Residual Weight Ratio (Chair)

Table 2 shows the ranked time to reach the peak rate of heat release, which is the result of Babrauskas (2). In his experimental the ignition source was a gas burner having a heat release rate of approximately 50kw for 200 sec. This source simulated the performance of a wastebasket placed adjacent to the left chair arm. These peak times nearly coincide with the peak times of the mass burning rates. Therefore it shows that the effects of fabric and padding materials, whether PU foam, cotton

or mixed, on the time to peak appear, and that the peak times are around 250 sec $\pm$ 30 sec for PU foam padding and polyolefin fabric. But it can be noted that foam type had no effect on the time to peak.

In the present experiments, ignition sources that are smaller than Babrauskas' source were used. They were either solid methanamine pills (2 pieces) or a tablet set on the seat of the chair or settee. The location on the seat was varied from a test to another. Clearly some of the scatter in the T_p values is a result of the small size of and varying location of the ignition source. Nevertheless, the present results tend to be in qualitative agreement with those of Babrauskas. More systematic experiments may allow one to grade ignition source and fabric material such that T_p for an upholstered chair can be predicted.

The values of r of chair are more scattered than in wood crib but range between about 0.8 and 0.5 with a mean value around 0.7. It seems that r mainly depends on ignition source magnitude, ignition location, and chair con-

Table 2. Ranked peak times by Babrauskas (2)

Specimen	Time to peak (s)	Padding	Fabric
F22	910	Cotton	Cotton
F24	650	PU Foam, C	Cotton
F27	570	Mixed	Cotton
F33	560	Mixed	Cotton
F23	450	Cotton	Polyolefin
F28	420	Mixed	Cotton
F21	280	PU Foam, C	Polyolefin
F25	260	PU Foam, C	Polyolefin
F32	250	PU Foam, C	Polyolefin
F26	240	PU Foam, C	Polyolefin
F30	235	PU Foam, NC	Polyolefin
F31	230	PU Foam, C	Polyolefin
F29	220	PU Foam, NC	Polyolefin

PU : Polyurethane, C : California Foam
NC : Not California Foam

figuration. It should be possible to determine a specific value for r for each type of furniture according to specify ignition source and its magnitude.

The value of A would mainly depend on the flammability of the soft foam and configuration of the chair. The burning rate is high when the value of A is large. Therefore, if it is possible to group upholstered chairs into several types on the basis of burning rate, a value for A for each group of chairs can be determined from experimental results.

5. CONCLUSION

The burning rate is one of the key factors which describe the burning behaviour. The radiant heat flux and the smoke generation can be considered as a function of burning rate. The model of burning rate for furniture as described above may not be complete, but equation (3) with properly defined values for $\dot{m}$ adequately describes the burning rate of wood cribs, urethane foam, and upholstered

chairs. T_p , r and A can be determined for every chair by burning every chair. However, it is difficult to determine all the necessary parameters from only the present data, and burning every chair is impossible. Therefore it is necessary to conduct more systematic experiments which will show how T_p , r and A depend on materials and configurations for various classes of chairs. To get reproducible results in these systematic experiments the ignition source should be well defined and large like a wastebasket.

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