THE FLAMMABILITY OF COMPOSITE FABRICS

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PREFACE

There is a growing concern about the flammability of textiles, and a number of new standards are being drafted or revised in order to minimize the fire risks connected with the use of these materiails. The recent statistics published by the U.S. Department of Health indicate that the annual toll from burns associated with flammable fabrics amounts to 5,000 death and up to 250,000 non-fatal injuries. In terms of financial loss the yearly total exceeds a quarter of a billion dollars. Similar levels of fire losses were reported in the U.K. and other countries.

The new legislation extends flammability standards to cover fibre-reinforced plastics, foams, interior furnishings, apparel fabrics including hats, gloves, footwear, and interlining fabrics as well as a wide range of industrial textiles.

It is generally appreciated that the flammability is a complex phenomenon. Some of the flammability aspects like the rate of flame spread have been discussed at length, and in fact, numerous standards are based on these results. More recent studies of flammability of textiles confirm the view that smoke emission, presence of toxic gases, ease of ignition, heat evolution and oxygen depletion, are as important as the rate of flame spread in assessing the fire risks of textile materials. Much more, however, remains to be done. It is then clearly necessary to have an acceptable and meaningful method of assessing the flame resistance of materials.

Part one of the present investigation is therefore concerned with the development of a new equipment and test method which incorporates many of the recent concepts of fire hazard.

Part two is an account of a study of the flammability characteristics of blends of fibres carried out with the object of making a blend which will meet with both new and old specification and which is at the same time economically priced.

This work was facilitated by the development of a new simultaneous Thermal Analyses techniques which enabled the information to be obtained on very small amounts of material.

These studies have provided much new information on several inherently flame-resisting and flame-retarding fibres which because of their very high costs have not been systematically investigated in blends and which so far have found only a limited outlet in specific applications.

This volume is concluded by a proposed new classification of textile materials and blends based on new methods of flammability rating. Two novel methods of producing flame-resisting fibres used in current investigation are described in appropriate chapters.

The account of experimental studies carried out in part one and part two in this work is preceded by critical reviews of:

a. the flammability of textile materials as well as methods of reducing fire risks;

b. test methods for assessing the flammability of fibres, yarns, fabrics and films.

The greater part of the experimental work described in this book was carried out by the Author in 1969-1971 at the Department of Textile Industries, University of Leeds, U.K. An addendum of recent literature is provided at the end of the volume to up-date the work. Some of the fibres mentioned have undergone modification since being tested.

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ABSTRACT

There are about 1,000 deaths each year due to burns in the United Kingdom. Figures of deaths do not however indicate the true size of the problem. It has been reliably estimated that at any one time there are some 550 people in hospitals in this country under treatment for burns, two-third of them for clothing burns, and that there are in the community today about 136,000 people who at sometime or other have been severely burned by their clothing catching fire and who need hospital treatment, many of them suffering from permanent after effects. It has recently been reported in the U.S.A. that 5,000 Americans die and 150,000 to 250,000 are injured each year from burns caused by flammable fabrics, and that the cost of medical care for the hospitalised burn victims has been estimated to total about 200 million per year.

The present methods of chemical flameproofing of textiles are critically reviewed.

It has been shown that in general the "added on" finishes frequently lose their flame-resisting properties after several dry cleanings or washings in detergents and their effectiveness seldom lasts during the whole life of the fabric. Further, these flame-proofing treatments are affecting other desirable fabric properties like handle softness or appearance.

There are several inherently flame-retarding fibres which can be described as non-flammable. However, their use is very limited due to their very high cost, and mainly due to this reason they have not been systematically evaluated in textlie blends. It has been shown that the flammability behaviour of fabrics made from two component blends of a non-flammable and a combustible fibre or of two non-flammable fibres cannot be accurately predicted and must be determined experimentally. To compare the flammability performance of experimental blends on the same basis a "model fabric" was designed and over 100 blends were evaluated, using specially developed equipment and methods of testing. A critical review of existing standard testing methods have shown that they do not adequately judge fire hazard of textile materials. The shortcomings of currently applied tests can be summarized as follows:

1. Some of these tests have been set at an arbitrary time or distance of burning which was chosen without any regard for any real situation.
2. The flammability rating of a material is often more dependent

on the particular test or test configuration chosen rather than on the inherent property of the material.

3. Some of the standard tests are of the "pass—no pass" type which determine only whether the specimen of material will burn in air while placed in an arbitrary test configuration, so the results are of little value in studying the material itself.

4. Most of these tests make no distinction between very flammable and non-flammable materials.

5. In general the tests have little relationship to each other, and their relationship to any actual end-use conditions has frequently been criticised.

The above considerations have prompted a decision to develop a new equipment and a more meaningful flammability testing method.

The main aim in designing the new equipment was to eliminate as far as possible the above-listed shortcomings, and to provide an apparatus capable of determining in one test, simultaneously and quantitatively, the most important inherent flammability characteristics of materials subjected to combustion. These characteristics should be determined preferably at their critical oxygen level or at any other, but closely controlled, oxygen concentrations.

The tested characteristics are:

1. ease of the ignition or critical oxygen level;
2. temperature profile in ignited material from which can be deduced:
   (i) rate of flame spread
   (ii) maximum temperature
   (iii) total heat output
   (iv) afterglow, reignition;
3. emission of smoke from the material under both flaming and smouldering conditions;
4. emission of toxic gases — carbon-monoxide in particular — under both flaming and smouldering conditions;
5. rate of oxygen depletion due to the burning of the material in enclosed chamber and in a standard atmosphere.

The main factors considered in designing this equipment were as follows:

(a) the determination of the main aspects of flammability should be reproducible,

(b) carried out using the same specimen simultaneously, and

(c) the equipment should be easy to operate.

The new equipment should also be applicable to a wide range of materials.

The decision to use the critical oxygen level as a base for all aspects of flammability determinations was taken due to the following considerations.

1. In many initial stages of fires, materials only just burn in the depleted oxygen, thus, in the proposed method, the flammability performance of materials is determined in conditions which may be encountered in real fire situations.

2. All materials are being tested under threshold conditions of "just burning".

3. Because the proposed test is based not on unrealistic arbitrary parameter but on a closely defined and inherent critical oxygen level of materials it has been shown to be highly reproducible within one laboratory and on an inter-laboratory basis.

4. The critical oxygen level as a basic physical parameter permits testing of a wide range of materials. For testing of materials in the current work, unheated atmosphere was used, but for special tests elevated temperatures and higher oxygen concentrations can be employed.

5. Test results obtained using the FTA module tester indicate that each material has its own clearly defined critical oxygen level and that even 0.2% difference in oxygen concentration decides whether material will ignite or the flame will be extinguished. Further, even a small change in oxygen concentration directly affects all other flammability aspects. For these reasons, the flammability testing should be carried out at a closely-controlled oxygen concentration, preferably at an inherent critical oxygen level of the tested material.

The test results of the main parameters contributing to the flammability of materials, viz, ease of ignition, rate of flame spread, heat output, smoke and toxic gases emission, are expressed in various units of widely differing average dimensions. Further, they are also expressed in a form where a larger figure does not always indicate an improvement in flame resistance. This makes comparison among the large amount of data rather difficult and it is proposed to convert these values into dimensionless ratings in such a way that:

(a) the larger the unit the more flame resistant is the material; and

(b) that 100 unit represents as far as possible the highest value of the rating which would be obtained in practice, while zero would represent the worst possible value.

The conversion formulae chosen are obviously arbitrary, but it is possible to find the basic data from the rating itself if required.

The individual ratings used in this work are defined as follows:

The ease of ignition was defined as

$$Ra = \frac{x}{25} \times 100$$

where x is the critical oxygen level found in the test procedure.

Flame spread rating has been defined as

$$Rb = \frac{y}{100} \times 100$$

where y is the inverse of the rate of flame spread in seconds per inch.

Heat output rating was defined as

$$Rc = \left(1 - \frac{z}{1000} \right) \times 100$$

The smoke emission rating was defined as

$$Rd = \frac{(100 - S)}{100} \times 100$$

where S is the per cent of visual obscuration recorded.

Toxic gas rating was defined as

$$Re \frac{(1000 - t)}{1000} \times 100$$

where t is the emission of CO in ppm.

Based on the above individual parameters the Material Flammability Rating is expressed as follows:

$$MFR = (Ra + Rb + Rc + Rd + Re)$$

The Critical Oxygen Values (COL) were taken as indicative of ignitability behaviour in the Standard Vertical test for a broad spectrum of fibre compositions. Generally, fabrics with a COL 26.0 pass the Vertical test and fabrics with a COL 24.0 fail. In the COL range of 24.0 to 26.0 the flammability behaviour of fabrics in the Vertical test cannot be confidently predicted. This problem was solved using broader MFR basis incorporating not only COL (ease of ignition) but also of other above described parameters of flammability.

From the experience gained and based on the proposed test procedure a simple classification of the flammability of materials is suggested below.

Class 1	Fire-resisting Materials	MFR 400 and over
Class 2	Flame-resisting Materials	MFR 350 and over
Class 3	Flame-retarding Materials	MFR 315 and over
Class 4	Low-Flammability Materials	MFR 290 and over
Class 5	Flammable Materials	MFR under 290

The test results based on 56 standard blends indicate a good reproducibility. The Confidence Limits of individual flammability parameters were found to lie within a $\pm 5\%$ range and for the overall flammability rating of materials (MFR) to lie within $\pm 7\%$ range.

CONTENTS

1

TEXTILES AND FIRE HAZARD, FIRE FREQUENCIES AND FATAL INJURIES

1.1. *Introduction*

The total U.K. fire damage is increasing every year and in 1971 it exceeded £120 million as paid in insurance claims. The sums quoted do not take full account of losses due to disruption of production and human suffering. The figures related to fire losses in the U.S.A. are simply staggering. In 1969 there were about 2½ million cases of fires of all types causing property damage loss of 2,447,600,000 dollars.

Textiles contribute considerably to these fire losses. Appendix 1 of this work provides statistical data of frequencies and rankings of some industries in Great Britain and in the U.S.A. in accordance with their relative fire hazards.[1,2,3,4] It may be observed from the data of frequencies that the textile industry and textile finishing works in particular show one of the highest fire hazards in both the United Kingdom and the U.S.A. With regard to fire costs the textile industry in the U.K. was at the top of the list in 1969 with 76 large fires costing £8.5 million. The years 1970 and 1971 were even worse in this respect. The actual known hazards of various classes of textiles will be considered in detail.

1.2 *Industrial Textiles*

These materials have often been a prime source of some very severe fires, thus those connected with the coalmining industry in the United Kingdom will still remember that 150 miners perished in a fire at the Cresswell Colliery where the industrial textile, a rubber coated conveyor belting, ignited due to friction and spread the fire throughout the coalmine with most tragic consequences.

A vestibule cloth on British Railways, a flexible plastic coated fabric, fixed between two coaches, is yet another example of an industrial textile which in the past caused several fatal fires. Both examples, the conveyor belting and the vestibule cloth, forced legislators, after tragic events, to introduce non-flammable standards covering these fabrics. For example, the fire resistance of conveyor belting for use in coal mines must now meet the requirements of N.C.B. Specification No. 158/1960 and B.S. 3289-1960.

1.3 *Clothing*

There are about 1000 deaths each year (250 clothing fires) due to burns in the United Kingdom. Figures of deaths do not, however, indicate the true size of the problem. The total number of burning accidents, fatal and non-fatal, is unfortunately not recorded, but it has been reliably estimated that at any one time there are some 550 people in hospitals in this country under treatment for burns, two-thirds of them for clothing burns, and that there are in the community today, about 136,000 people who at some time or other have been severely burned by their clothing catching fire, and who need hospital treatment, many of them suffering from permanent after-effects. It has recently been reported in the U.S.A. that 3,000 to 5,000 Americans die and 150,000 to 250,000 are injured each year from burns caused by flammable fabrics[6], and that the cost of medical care for the hospitalized burn victims has been estimated to total about $170 million per year.[7]

In the Appendix to this chapter, data collected over a two-year period has been given, relating to single fatality fires, and an analysis of 670 deaths is discussed in detail.

The proportion of burning accidents in which clothing is involved has also been recorded by the Birmingham Accident Hospital; out of 701 cases of domestic burns admitted to the hospital, 352 of these were caused by clothing fire.

Recently McDonald, Dardis and Smith have published a comprehensive review of accidental burn injuries.[8]

With regard to clothing, it was reported in data collected by the U.S. National Burn Information Exchange that two out of every three burns involved fabric ignition.[9] An Oklahoma survey of causes of burns from 1954 through to 1958 found that 28 out of 29 fatal burn cases involved clothing ignition.[10] In contrast only 39% of the known causes of deaths from burns and explosions in the home in Kansas from 1958 through to 1962 were attributed to clothing ignition.[11] In a recent study of burn injuries, McDonald[12] found that textile products were most frequently the primary agent ignited (33%) with flammable liquids second (25%). Household textile items accounted for 71% of the textile products ignited, and apparel items the remaining 29%. The source of ignition in most cases was smoking or matches.

In Birmingham, England, Colebrook and others reported an increasing incidence of clothing burns from 1945 to mid-1955 (36% to 50%), and they were to most severe cases.[13,14,15] In these studies, the mortality rate for clothing burns alone, was almost double the rate for all burns (23% as compared to 12%). Bull et al[16] continued the review of burn cases in Birmingham and reported that clothing continued to be a significant factor in flame burns. Some 743 of 1,322 burns (56%) that occurred in the home from mid-1955 through to 1962 were associated with flammable apparel. Women and the elderly were most susceptible to clothing burns.

Williams-Leir[17] examined fatal clothing and bedding fires separately. Contrary to what Colebrook and Bull found, Williams-Leir indicated that males were most often involved in fatal clothing fires (57%). Flammable liquids were associated with 16% of the clothing fatalities.

In the case studies of burned children, clothing was also found to play a significant role. Wilkinson found that clothing was ignited in 30 out of 68 (44%) non-scald burns, and caused six fatalities. The mortality rate of 20% for clothing burns, was twice the mortality rate for all burns.[18]

Bleck[19] examined the cause of 344 cases of burns to children, and found four main causes. Nearly half (46%) of the burns were caused by clothing ignition, and girls were more often injured that boys (61%). Direct contact with flame, hot ashes, and stoves (26%), flammable liquids (15%) and hot liquids (8%) were the other three major causes, and boys were most often injured.

Forty-one per cent of 142 flame burn and scald accidents to Tennessee children were caused by clothing ignition.[20] Lesser incidences were reported in other studies of burns to children by Chambers[21] (24% of non-scald burns), Munro et al[22] (14% of non-scald burns). Flammable liquids caused most of the non-scald burns in the study (20%). Innes reported that of 215 burns to children, 23% involved flammable liquids and clothing together.[23]

In the study of textile fires by the Consumer Protection and Environmental Health Service only 16 of the 329 cases involved non-garment ignition.[9] The garments most frequently mentioned were shirts, blouses, night clothes and trousers. Fibre content was given for only 187 of the total 486 garments involved. Cotton was the leading fibre (75%) followed by nylon (8%) and other man-made fibres (8%). Twenty-one of the 30 fatalities were male, which is in agreement with the results of Williams-Leir.[17] Six of the fatal accidents involved flammable liquids on clothing (20%).

The severity of injury is often expressed by case mortality figures, or by mean length of hospital stay. As indicated in the previous section, the case mortality rate was highest for injuries involving apparel ignition. Those accidents also required longer hospitalization than all burn cases combined.[13, 24, 15] A severity rating developed by the Tennessee Public Health Department and used to evaluate burn accident cases found that clothing fires were the most severe.[20]

Surveys conducted in the U.K. by the Burns Unit of the Medical Research Council show that the average period of hospital in-treatment for a clothing burn is 48 days, against 26 days for other burns.

The various effects of thermal injury by heat transfer through the fabric was recently discussed by Stoll[25] and others.[26, 27] Snyder[28] reviewing thermal injuries has also confirmed that burns are responsible for more hospital days than any other injury.

Table 1. Analysis of Clothing Fires[29]
(300 case histories—1968)

	Per cent
Burn Cases Involving Males—Adults	
Shirts	45
Trousers	26
Miscellaneous	29
Burn Cases Involving Females—Adults	
Nightwear	41
Sweaters	17
Blouses	15
Bathrobes	11
Miscellaneous	16
Burn Cases Involving Children	
Nightclothes	40
Shirts and Blouses	35
Miscellaneous	25

Table 1 indicates that nightwear constitutes a considerable fire hazard[25] and this applies particularly to children's sleepwear.[26]

The review of clothing fires explains why new legislation is often proposed to strengthen the flammability standards for specific end use fabrics, and the proposed U.S. Flammability Standard relating to children's sleepwear is one example of this new trend.[30] This specification defines sleepwear as any product of wearing apparel up to and including size 6 (Commercial Standard CS 151–50) and this includes nightgowns, pyjamas or similar or related items such as sleeping robes.

The proposed Standard was the result of laboratory information classified under 3 headings:

1. tests on remnants recovered from accidents,
2. tests on purchased children's sleepwear garments, and

INDEX