Fire Performance of Plastics

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FIRE PERFORMANCE OF PLASTICS

A Review of RAPRA Work

by

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Foreword

The work conducted at RAPRA in studying the fire performance of plastics was commissioned by the British Plastics Federation's Building Group with the support of the Department of Trade and Industry (during the period 1967-Oct. 1970). The objective of the study was to determine any extra hazards which might arise from an increased use of plastics in building whether this hazard be due to an increase in the risk of a fire being initiated, an increase in the speed of fire propagation or an unacceptable increase in the amount of smoke and toxic products generated. It must be generally recognised that any combustible material is likely to present a hazard in a fire; however it does not follow that combustible material will increase the hazard which exists in a fire. The position is complex and one might find for example that the cost of reducing the ignitability and flammability of a material would be an increase in the amount of smoke generated by that material when it is fully committed to a fire. However safety in a public place would depend to a very large extent on the time taken for untenable conditions to be established, and self-extinguishing plastics materials may have an important part to play in this sphere. The work at RAPRA examined the relative performance of individual materials in a variety of fire test environments which included standard and non standard test procedures used in the U.K. and abroad. New standard tests have been examined critically with a view to improving their reproducibility; and RAPRA has collaborated closely with the JFRO and the BSI in trying to effect improvements in the important Fire Propagation Test of BS 476 Part 6 and the Smoke Test being proposed for BS 476 Part 9.

In carrying out tests consideration was given to the possible effects the materials could have in a real fire environment and the value of large scale tests was demonstrated.

The first two Parts of this collection of RAPRA Reports are literature reviews of test methods and smoke and toxic products. These are followed by reports of RAPRA work on smoke and toxic gases from unplasticised PVC; fire propagation and other tests; and flammability tests.

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FIRE PERFORMANCE OF PLASTICS: METHODS OF TEST

N.K. Raman, K.A. Scott and W. Taylor

INTRODUCTION

The term "plastics" refers to a very wide range of synthetic and modified natural polymers which are being used in a very wide range of applications. The behaviour of plastics in fire ranges from highly combustible through to inorganic polymers which are virtually incombustible. Most polymers fall between these two degrees of combustibility and a variety of terms are used to describe the burning characteristics. These include "difficult to ignite" and "self-extinguishing" which have meaning only in terms of a defined test procedure.

This review summaries tests which have been used to define the fire performance of combustible materials including plastics. Many of the small scale tests are intended to classify the characteristics of materials in the form of small standard test specimens and seem to bear little relationship to the final application (see ASTM D635 BS 2782 Method 508A, ASTM 1929 etc.). Other tests expose a standard specimen to conditions which might prevail in the application (see BS 476 Part 1, BS 476 Part 6 globar, electrical spark ignition test etc.). The multiplicity of tests reflects efforts to develop relevant procedures but they often suggest a lack of co-ordination or a psychological need for the developers to make their mark - note the series of tests ASTM D635, BS 2782 Method 508A, BS 3532 etc.

At RAPRA the fire performance of plastics is being studied using standard tests and non-standard environmental tests. This review was prepared as part of a consideration of "relevant" tests and to establish what procedures were already available. An attempt has been made to group tests into a logical order but this has not been possible throughout because of some multiple purpose tests. Where available tests for smoke and toxic combustion products have been included. Reference is made to published environmental tests but it is not suggested that these are sensible standard classification tests.

Apart from laboratory tests in many countries, some establishments are undertaking full scale tests involving the use of a large burning chamber with an adjoining corridor. This arrangement enables one to study the fire behaviour of large quantities of materials. Among the notable technical establishments carrying out such tests are:-

The Illinois Institute of Technology, Chicago, U.S.A.

The Danish Institute of Building Research, Copenhagen, Denmark.

Full scale fire tests are also being carried out at Shawbury by RAPRA Staff.

TYPES OF FIRE TEST

Fire tests can be classified according to the flammability characteristics which they are designed to measure. The available tests can be broadly made to fit into one of the following descriptions.

IGNITABILITY AND FLAMMABILITY

Tests for ignition determine how easily and under what conditions a material will ignite. For a fire to exist it must first start; thus the ignition characteristic is quite as important as the burning rate.

Tests for flammability measure the rate at which materials burn. This group also includes surface flammability more commonly referred to as "surface spread of flame tests". BS 476 Part 1 Section 2 is at present used in U.K. Building Regulations to grade materials into different classes.

HEAT CONTRIBUTION

These are generally calorimetric type of tests but certain flammability tests, for example, the fire propagation test BS 476 Part 6 can be included in this category.

FIRE ENDURANCE

Fire endurance tests are normally associated with structural systems rather than individual materials.

SMOKE GENERATION

Tests for smoke generation usually involve measurement of light absorption or sight obscuration.

FIRE GASES

Tests for fire gases involve collection of atmospheric samples in the vicinity of the test and subsequent analysis of these samples.

TESTS AVAILABLE

A large number of test methods have been proposed and specified for assessing the fire behaviour of plastics. Many of them are modifications of a basic standard method which is changed either in the detail of procedure or in the interpretation of results. This range of test can often lead to confusion. In this review it is proposed to deal mainly with British and ASTM tests and also indicate some of the more important tests used in other countries.

TESTS FOR IGNITABILITY & FLAMMABILITY

Most organic materials ignite given enough heat, oxygen and time and the ease of ignition can be measured by the amount of heat required under fixed conditions of oxygen and time. Ignition can also be determined by fixing any two of these parameters and varying the third.

ASTM D-1929 SETCHKIN TEST (1) (Figure 1)

This test (which measures ignition temperature) employs a vertically heated furnace tube 22 cm. long with a 19 cm. bore heated by electrical current passing through michrome wire in an asbestos sleeve wound around the tube and a inner refractory tube 22 cm. long with a 7.6 cm. bore inside which the specimen is placed. Air is admitted at a controlled rate and its temperature measured by means of thermocouples. The ignition temperatures can be determined both by the rising temperature method and the constant temperature method but the latter method is very time consuming. Published results obtained from this test are shown in Table 1.

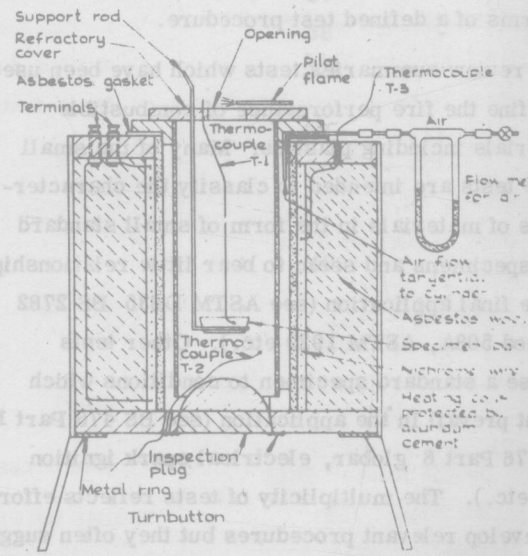

Fig. 1

Table 1 Ignition Temperatures of Various Materials - Setchkin Test

Material	Flash-Ignition Temp. °C	Flash-Ignition Temp. °F	Self-Ignition Temp. °C	Self-Ignition Temp. °F
Cotton	230-266	446-511	254	490
Paper, newsprint	230	445	230	445
White pine, shavings	228-264	406-507	260	500
Long leaf pine	220-230	428-446		
Douglas fir	260	500		
Wool	200	401		
Polyethylene	341	645	349	660
Polypropylene, fibre			570	1058
Polytetrafluoroethylene			530	986
Polyvinyl chloride	391	735	454	850
Polyvinyl chloride-acetate	320-340	608-644	435-557	815-1035
Polyvinylidene chloride	532	990+	532	990+
Polystyrene	345-360	653-680	488-496	910-925
Polystyrene, beads	296	565	491	915
Polystyrene, foam beadboard	346	655	491	915
Styrene-acrylonitrile copolymer	366	690	454	850
Styrene-methyl methacrylate copolymer	329	625	485	905
Polymethyl methacrylate	280-300	536-572	450-462	832-864
Acrylic, fibre			560	1040
Cellulose nitrate	141	286	141	286
Cellulose acetate	305	581	475	887
Cellulose triacetate, fibre			540	1004
Ethyl cellulose	291	555	296	565
Polyamide (nylon)	421	790	424	795
Nylon 66, fibre			532	990
Phenolic, glass fibre laminate	520-540	968-1004	571-580	1060-1076
Melamine, glass fibre laminate	475-500	887-932	623-645	1153-1193
Polyester, glass fibre laminate	346-399	655-750	483-488	811-910
Polyurethane, polyether, rigid foam	310	590	416	780
Silicone, glass fibre laminate	490-527	914-981	550-564	1022-1047

ASTM D-2863-27 THE OXYGEN INDEX TEST

(2, 3, 4) (Figure 2)

This test also known as the Fenimore-Martin oxygen index test employs a vertical glass tube 60 cm. high and 8.4 cm. in diameter, in which a rod or strip specimen 8 cm. long is held vertically by a clamp at its bottom end. A mixture of oxygen and another gas or gases, usually nitrogen is metered into the bottom of the tube passing through a bed of glass beads at the bottom to smooth the flow of gas. The sample is ignited at its upper end with a hydrogen flame which is then withdrawn and the atmosphere that permits steady burning down of the specimen is determined. The limiting oxygen index is the minimum fraction of oxygen in an oxygen-nitrogen mixture which will just permit the sample to burn. Materials which have a limiting oxygen index

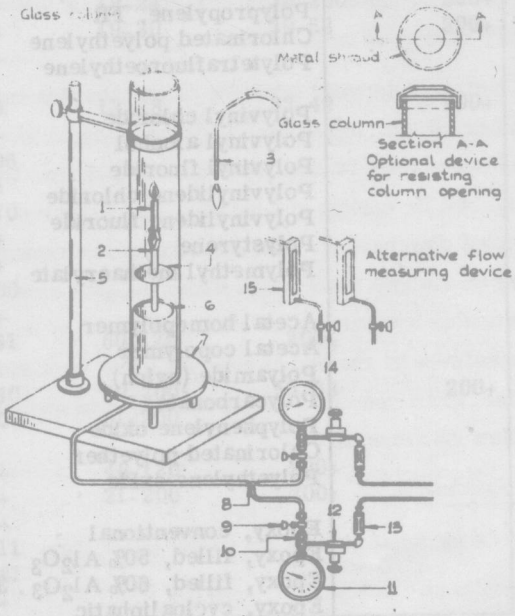

Fig. 2

greater than 0.21 are self-extinguishing after ignition in air if allowed to burn in the same manner as the test from the top down but a "self-extinguishing" rating in a more severe exposure would probably correspond to a significantly higher limiting oxygen index. Some published results of this test are given in Table 2. A similar instrument has been developed by the Michigan Chemical Co., U.S.A. but in addition to measuring the limiting oxygen index this method also measures the average smoke density of the specimen under investigation.

THE ASTM E 136 TEST (5) uses essentially the Setchkin apparatus to determine non-combustibility by placing a specimen 3.8 cm. by 3.8 cm. by 5.2 cm. in an airstream maintained at 1382 $\pm$ 10°F.

AN UNDERWRITERS LABORATORIES TEST FOR IGNITION TEMPERATURE (6) employs a high temperature glass flask surrounded by a molten alloy bath heated by an electric furnace. The flask is conical with a flat bottom 6 cm. in diameter 11.4 cm. high and 2.8 cm. in diameter at the top giving a total volume of 160 ml and a surface area to volume ratio of 1.1 cm^{-1}. Specimens are dropped into the flask after the temperature has reached equilibrium at a selected value and are checked for ignition. Because this test provides conditions of natural convection inside the flask rather than controlled air flow, its results are not necessarily the same as those obtained with the Setchkin test.

There are two further ignitability tests developed by the Underwriters Laboratories. The first is the hot wire ignition test (6) which employs a specimen wrapped with five turns of 24 gauge soft iron or turned copper wire, which is then heated to glowing by passage of electrical current.

Table 2 Limiting Oxygen Concentration for Various Materials (Fenimore-Martin test)

	$n_{O_2} / (n_{O_2} + n_{N_2})$
Paraffin, candle	0.16
Carbon, porous	0.559
Carbon, electrode	0.635
Polyethylene	0.174 to 0.175
Polyethylene, filled, 50% Al_2O_3	0.196
Polyethylene, filled, 60% $Al_2O_3 . 3H_2O$	0.302
Polypropylene	0.174
Polypropylene, filled, asbestos	0.205
Polypropylene, FR	0.282
Chlorinated polyethylene	0.211
Polytetrafluoroethylene	0.95
Polyvinyl chloride	0.45 to 0.49
Polyvinyl alcohol	0.225
Polyvinyl fluoride	0.226
Polyvinylidene chloride	0.60
Polyvinylidene fluoride	0.437
Polystyrene	0.181
Polymethyl methacrylate	0.173
Acetal homopolymer	0.150
Acetal copolymer	0.148 to 0.149
Polyamide (nylon)	0.29
Polycarbonate	0.26 to 0.28
Polyphenylene oxide	0.28 to 0.29
Chlorinated polyether	0.232
Polyethylene oxide	0.150
Epoxy, conventional	0.198
Epoxy, filled, 50% Al_2O_3	0.250
Epoxy, filled, 60% $Al_2O_3 . 3H_2O$	0.408
Epoxy, cycloaliphatic	0.198

The second, the arcing test (6), subjects the specimen to 40 applications per minute for a maximum of 5 minutes of an electric arc fed by a 33-amp current from a 240 volt power supply. Selected results obtained from this test are given in Table 3.

Similar electrical service tests developed by Underwriters Laboratories are the high voltage arc resistance test and the high voltage arc tracking test (6).

The ASTM D 229 test (7) for rigid sheet and plate materials used for electrical insulation employs a vertical specimen measuring 28 cm. by 1.3 cm by 1.3 cm. surrounded by a heater coil of michrome resistance wire maintained at 860 ± 50°C by the passage of approximately 55 amp of electrical current. Continuous sparking is provided to ignite evolved gases. This test gives both ignition time and burning time.

The Federal Test Method Standard 406 (Method 2023) is similar to ASTM D 229 except the specimen size is 13 cm. by 1.3 cm. by 1.3 cm.

BS 476: Part 5 (1968) - IGNITABILITY TEST FOR MATERIALS

The apparatus consists of a U-frame of 9 mm mild steel rod or tube fixed to a rigid steel base. The

Table 3 High Current Arcing Ignition of Various Materials - UL test (Number of Arcs Required to Ignite)

Distance of electrodes from surface, inches	0	1/16	1/4	1/2
Polyethylene	79-182	49-57	70-200	200+
Polyethylene, medium density	77-120	88-103	200+	
Polyethylene, FR	200+			
Polypropylene	81-170	33-51	27-200	200+
Polytetrafluoroethylene (TFE)	200+			
Fluorinated ethylene-propylene (FEP)				200+
Polyvinyl chloride, rigid	200+			
Polyvinyl chloride, semi-rigid	200+	30-84	51-200	200+
Vinyl chloride-vinylidene chloride	29-33	65-83	200+	
Polystyrene, general purpose	27-82	29-34	200+	
Polystyrene, general purpose, FR	139-200		53-63	200+
Polystyrene, medium impact	24-29	28-63	52-200	200+
Polystyrene, high impact	31-150	49-59		200+
Polystyrene, high impact, FR	183-200	32-47	85-200	200+
Styrene-acrylonitrile copolymer (SAN)	35-53	72-117	45-200	200+
Acrylonitrile-butadiene-styrene (ABS)	35-75	18-24	38-200	200+
ABS, heat resistant	18-65	19-30	30-52	200+
Polymethyl methacrylate	200+			
Cellulose acetate	24-30	13-28	33-49	200+
Cellulose acetate, FR	200+			
Cellulose acetate butyrate	25-106			
Cellulose acetate propionate	52-85			
Polyformaldehyde	84-170			
Nylon 6	200+			
Nylon 6/6	200+			
Nylon 6/10	85-200			
Chlorinated polyether	200+			
Polycarbonate	40-131	60-125	200+	
Phenol-formaldehyde	65-140	60-200	55-68	200+
Phenol-formaldehyde, heat resistant	36-200	61-200		
Melamine-formaldehyde	200+	46-120	200+	
Melamine-formaldehyde, glass fibre	200+	21-200	200+	
Urea-formaldehyde, FR	200+			
Polyester, FR	76-111			
Polyester, glass fibre	164-181			
Polyester, glass fibre, FR	200+			

frame is provided with two clamps fixed at mid-height to hold the specimen centrally. Two supports of the same section as the frame are fitted vertically to the base so that the lower edge of the specimen rests on them in its testing position.

A copper tube with one end reduced to a 1.5 mm diameter orifice is pivoted on a fixed strap attached to the base and provided with an adjustable stop so that when set in its testing position the tube is inclined at an angle of approximately 45^{o} to the vertical and the centre of the orific is 3 mm from the centre of the specimen.

The test is carried out in a draught free atmosphere. The specimen held vertically by clamps is ignited for 10 seconds by a gas jet. After 10 seconds the jet is moved away quickley and note made of the subsequent duration of flaming, if any, to the nearest second.

The material is classified as either, "easily ignitable" (X) or "not easily ignitable" (P). Those specimens which continue to burn more than 10 seconds after the removal of the gas jet receive 'X' classification while 'P' classification applies if the burning is less than 10 seconds provided the flame has not reached the edge of the test specimen.

BS 4735 - IGNITABILITY TEST FOR CELLULAR RUBBER AND PLASTICS

This test describes a small scale laboratory screening procedure for comparing the relative ignitability and self-extinguishing characteristics of plastics and rubber cellular materials exposed to a low energy source of heat.

The test arrangement consists of an asbestos test chamber 60 cm. by 30 cm. by 76 cm. (high) in which specimens 15 cm. by 5 cm. by 2.5 cm. (thick) are ignited by means of a propane gas burner of specified dimensions. Ten specimens are normally tested on the gas holder/specimen support arrangement and an average value obtained. Before testing the specimen is marked across its width by a line 2.5 cm. from one end. The gas burner is switched off after 60 seconds.

Calculations

If the flame front passes the gauge mark then

$$\text{Burning rate} = \frac{125}{t_g} \text{ mm/s}$$

where t_g is the time(s) at which the flame reaches the gauge mark.

If the flame front does not reach the gauge mark, then

$$\text{Burning rate} = \frac{\text{Extent burnt}}{t_e} \text{ mm/s}$$

where t_e = time(s) when the flame is extinguished.

This test is based on ASTM 1692-68 and is very similar in the arrangement and test procedure (see p.17).

BS 476: PART 1 (1953) - SECTION 1 (SOON TO BECOME BS 476: PART 4) NON-COMBUSTIBILITY TEST (Figure 3)

This test is applied to materials used in the construction or finishing of a building or structure, in order to determine whether they are combustible according to one or more of the following definitions.

a. flames or
b. produces vapours which are ignited by the pilot flame or
c. causes the temperature of the furnace to be raised 50^{o}C or more above 750^{o}C.

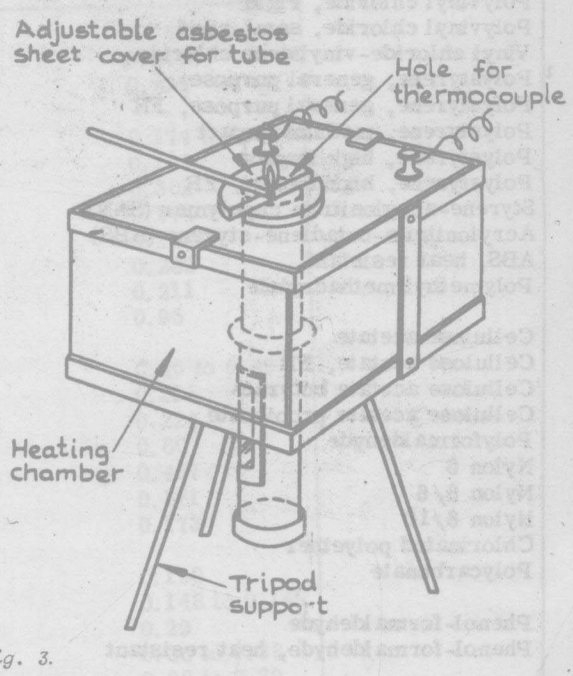

Fig. 3.

The test is carried out in the arrangement shown in Figure 3. A dried specimen 51 mm x 37 mm is placed in a vertical position in the furnace at 750^{o}C and heated for 15 minutes. The nature of the test specimen makes this unsuitable for plastics.

In the earliest tests the ignition temperature was measured by bringing a specimen in contact with a heated porcelain rod or immersing in a molten lead bath. The estimated temperature of the rod or bath (when the specimen ignited) was called the ignition temperature (8). In another test the specimen was placed in a bath of sodium hydroxide and the ignition temperature was that at which the specimen ignited in 10 seconds (9). In another test the surface temperature of a plastic was recorded when it ignited in a controlled furnace.

THE NEMA SWITCH GEAR TEST; A MODIFICATION OF US FEDERAL SPECIFICATION LP 406b (10)

US FEDERAL SPECIFICATION LP 406b METHOD 2023 - SPECIMEN HELD VERTICALLY

This test uses a standard 5" x 2" x $\frac{1}{2}$" specimen cut from nominal stock. The specimen after conditioning is weighed to the nearest 0.01 gms and placed in a holder. An arc circuit, heater circuit and timing circuit are simultaneously closed when the specimen ignites the ignition time is recorded. At the end of 30 seconds burning the spark and heater circuits are opened and the spark electrodes are moved. The specimen is allowed to burn in a draught. The burning time which starts when the heater circuit is opened and ends when the flame is extinguished is recorded. The specimen is then allowed to cool and is weighed.

The apparatus is said to record ignition time satisfactorily but difficulties occur in obtaining reproducible burning time results because the flame tends to splutter - i.e. is nearly extinguished and then recommences to burn vigorously.

A modified version of this test is used in an evaluation of flame retardants for polyester laminates and moulding compounds by G.W. Burton (11).

THE IBM ELECTRIC ARC TEST (10)

The test specimen is mounted above two tungsten electrodes which are spaced 3/8" apart and are connected to a 9000 volt, 30ma power supply. A sequence timer controls the duration of arcs as well as the interval between successive arcs. The number of arcs applied to the specimen to bring about ignition is used as a measure of the ignition characteristics of the material.

PAINT RESEARCH STATION IGNITION TEMPERATURE TEST (12)

The principle of this test is to expose the specimen at various distances from a radiating source so as to establish definite radiation temperatures and to observe whether or not ignition takes place when a flame is applied under defined conditions.

A suitable thermocouple is attached to the centre of the test specimen which is exposed to a radiant heat source made up of three domestic electric fire elements each 9" x 3" and consuming 1 kw per hour. The temperature of the specimen is adjusted to definite temperatures up to 500°C by varying the distance between the specimen and the electric fire. The ignition point is taken as that temperature at which ignition occurs when a "cold" bunsen flame is allowed to play over the surface.

U.S.S.R. TEST. TEST FOR IGNITION AND SELF IGNITION TEMPERATURES

A cylindrical sample 10mm diameter and 20mm high is placed in a wire cradle which is lowered into a vertical muffle furnace. The temperature in the furnace is steadily increased; after every 30° -50°C an alcohol burner is directed onto the specimen. When the gases and vapours ignited the temperature (T) in the furnace and the time to ignition (r) are recorded. The ignition temperature of the specimens is then determined from a graph of $\log \frac{1}{r}$ against $\frac{1}{T}$. The Ignition Temperature corresponds to the point where the straight line graph bends, since, when there is vigorous evolution of gaseous products capable of ignition the rate of combustion changes rapidly. The Self Ignition Temperature is determined in the same apparatus without using an alcohol burner.

It was proposed that polyesters having an ignition temperature above 500°C and a self ignition temperature above 600°C should be described as difficultly inflammable or self extinguishing.

A comparison is made between results obtained with this test and the Fire Tube Test.

ISO RECOMMENDATION - DECOMPOSITION TEMPERATURE OF PLASTICS

A method for determining the decomposition tempera-

ture of plastics has been published by ISO (R 871). The method permits an evaluation of the fire hazard caused by plastics when exposed to high temperatures for a considerable length of time. The method does not give a direct measure of the flammability or rate of burning of the material itself. The polymer is heated under standard conditions until the gases evolved are ignited by a flame.

ISO TEST - R 1326 - RATE OF BURNING OF PLASTICS FILM

This test measures the flammability and burning rate of plastics in the form of film.

The test piece 25 mm in width by 450 mm in length is clamped vertically so that 430 mm of it is exposed below the clamp. The top of the bunsen burner flame is applied to the end of the specimen until it is ignited but not for longer than 15 seconds. The flame may be momentarily withdrawn as needed to establish that the specimen is ignited. If the specimen ignites, the shield in which the test is carried out is closed and a timer started when one charred edge reaches the lower gauge mark (gauges previously marked on the specimen) and stopped when the flame reaches the upper gauge mark. The elapsed time is recorded.

If the flame is extinguished before reaching the upper gauge mark, the timer is stopped and the time of extinguishing recorded.

Expression of results

The burning rate is calculated in mm^2 (or $inch^2$) per minute by dividing the area above the lower gauge mark which is burned, charred or melted off, by the time in minutes. This area is the product of the width of the specimen and the distance between the first gauge mark and the second gauge mark or the most distant flame damaged point on the specimen.

FLAMMABILITY OF PLASTICS IN THE FORM OF BARS

This test determines the flammability of plastics in the form of bars of 3 to 5 mm thickness.

A test specimen is supported horizontally by one end. The flammability of the bar is assessed after a gas flame has been applied to the free end for a fixed period of time.

The test piece 80 mm long, 10 to 15 mm wide and 3 to 5 mm thick is clamped horizontally by one end so that the width dimension is in the horizontal plane and the free length is at least 80 mm. The bunsen burner is adjusted with closed air ports while in the vertical position to produce a flame approximately 100 mm long.

Whenever it is desired to ignite the specimen, the burner should be fixed at an angle of 45^{o} from the horizontal and directed towards the unclamped end of the specimen so that the top edge of the burner is 30 mm below the bottom edge and 5 mm away from the end of the specimen. It should not be moved if the specimen burns away. After 60 seconds the burner is turned off. The burning time is checked by means of a stop watch from the moment at which the burner was turned off.

The test report should include among others the following information:-

a. burning time in seconds (shortest and longest)
b. particular observations during the test (way of igniting, formation of make and colour etc.).

An assessment of the burning characteristics in a major fire in building, for example, is best made under conditions which reproduce the high radiant heat which will be encountered under the worst possible conditions. These tests are on a fairly large scale and are expensive. They are used very frequently by specifying bodies. To decide whether or not a material is reasonable for large scale testing evaluation, small laboratory screening tests are used. In their review W.J. Sauber and G.A. Patten (13) classify burning tests into (a) screening tests, (b) materials and design tests, (c) engineering or structural tests.

Some tests are used to "screen" materials. These are tests on small samples which can be of considerable value in comparing the flammability characteristics of different materials, in controlling the manufacturing processes, or as a measure of deterioration or change in flammability rating prior to or during use. Correlation with flammability under actual use conditions are not necessarily implied. A large variety of screening tests are available and they reflect attempts to modify methods to make them more suitable for the material under