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Fire Behavior of Alternate Building Materials—Part I—RMP

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Abstract. Polymers are fast replacing the conventional building materials, mainly because of their scarcity and attractive properties. However, users are hesitant to accept these alternate building materials as the polymers are considered to be associated with fire hazards. Red mud plastics (RMP) is one such polymer which is finding acceptance albeit slowly. Fire behaviour of RMP is discussed and compared with some conventional materials with a view to present it as a viable alternate.

Key words: alternate material, RMP, fire behaviour

Introduction

With the increasing environmental hazard due to deforestation, the use of wood is being restricted in many countries. In addition large quantities of industrial wastes, e.g., red mud are being produced annually. An optimum solution to both these problems is the use of polymers that can incorporate these waste products mainly as fillers.

Besides the waste utilization, the basic purpose behind the development of RMP (Red Mud Plastic) was to overcome the shortcomings of the parent plastic PVC, which is one of the most important synthetic polymer in terms of its usage [1] (*Anon. British Plastics Federation, 1984*). The target was to develop a material which is unaffected by long exposures of UV radiation while maintaining it's flexibility and ductility over a long period of time. Thus making it suitable for out door purposes. Accelerated UV tests in laboratories as well as out door exposure tests have shown that RMP has these features. Basically, RMP is un plasticized polymer (e.g., PVC, polyester etc.) with red mud as filler at around 25% loading. Red mud is a waste product obtained as sludge from aluminum industries. The typical chemical composition of red mud in India are as given in Table 1 [1]. Red mud powder, which contains ample amount of ferro oxide and aluminum oxide, neutralizes the HCl gas evolved during decomposition of PVC. Thus during out door applications the highly stabilizing ferro oxide and aluminum oxide impart protection against UV action. Being inorganic in nature and as it replaces as much as 25% of the polymer in the composition red mud enhances the flame retardancy of the polymer. RMP can be further modified to suit the requirements for different applications such as door panel, flooring etc. by use of suitable additives and reinforcement [2]. It finds application in roofing sheets, pipelines, tiles, low-pressure drainage systems, water reservoirs and in the furniture industries.

However, being polymeric in nature, RMP finds hesitant acceptance on account of fire hazards associated with polymers in general. It is therefore essential to assess the

TABLE 1
Composition of Red Mud

Constituents	Percentage
Al_2O_3	19–20%
Fe_2O_3	28–38%
SiO_2	13–15%
CaO	10–11%
Na_2O	9–11%
TiO_2	3–8%

fire behavior of this material. Some of the fire characteristics of RMP sheets have been evaluated and discussed hereafter.

Non-Combustibility Characterstic

Non-combustibility is the property of a material to withstand high temperature without ignition. It is determined to ascertain whether the material will or will not contribute directly to the development of fire [2]. It is intended for the selection of materials, which while not completely inert can produce only a limited amount of heat and flame when exposed to a temperature of approximately 750°C.

Standard Test

The method of determination of Non-combustibility is specified in many international standards [3]. The apparatus consist of an electric tubular furnace having inner diameter of 75 mm and height of 150 mm. A resistance wire inside the furnace is wound in such a way that a temperature of 750°C is obtained (as measured by the thermocouple placed 10 mm away from the inner surface of the furnace) in the central part of the furnace. The cylindrical specimen of 45 mm diameter and 150 mm height is exposed to the test conditions by placing it at the center of the furnace. The resultant temperatures are recorded continuously for 20 min at three locations i.e. at the specimen center, on the specimen surface and the furnace temperature. The duration of sustained flaming, if any, above 5 s and the mass loss is also recorded.

The average rise in temperature above the furnace temperature, duration of sustained flaming and mass loss of specimens of a material are computed. The material is classified as "*Non-combustible*" if these values are within specified limits i.e. rise in temperature less than 50°C above the furnace temperature, duration of sustained flaming less than 20 s and mass loss less than 50%, otherwise it is classified in "*Combustible*." The test method used in the present study is as per the Indian Standard IS: 38081979 [4], which is identical to ISO 1182 [5] and similar to BS 476 part 4 [6] and ASTM E 136 [7].

Performance

Time-temperature curves obtained for specimens of RMP Sheet during the non-combustibility test are shown in Figure 1. The data obtained and the computed mean results are given in Table 2. The average initial furnace temperature was observed to be 749°C.

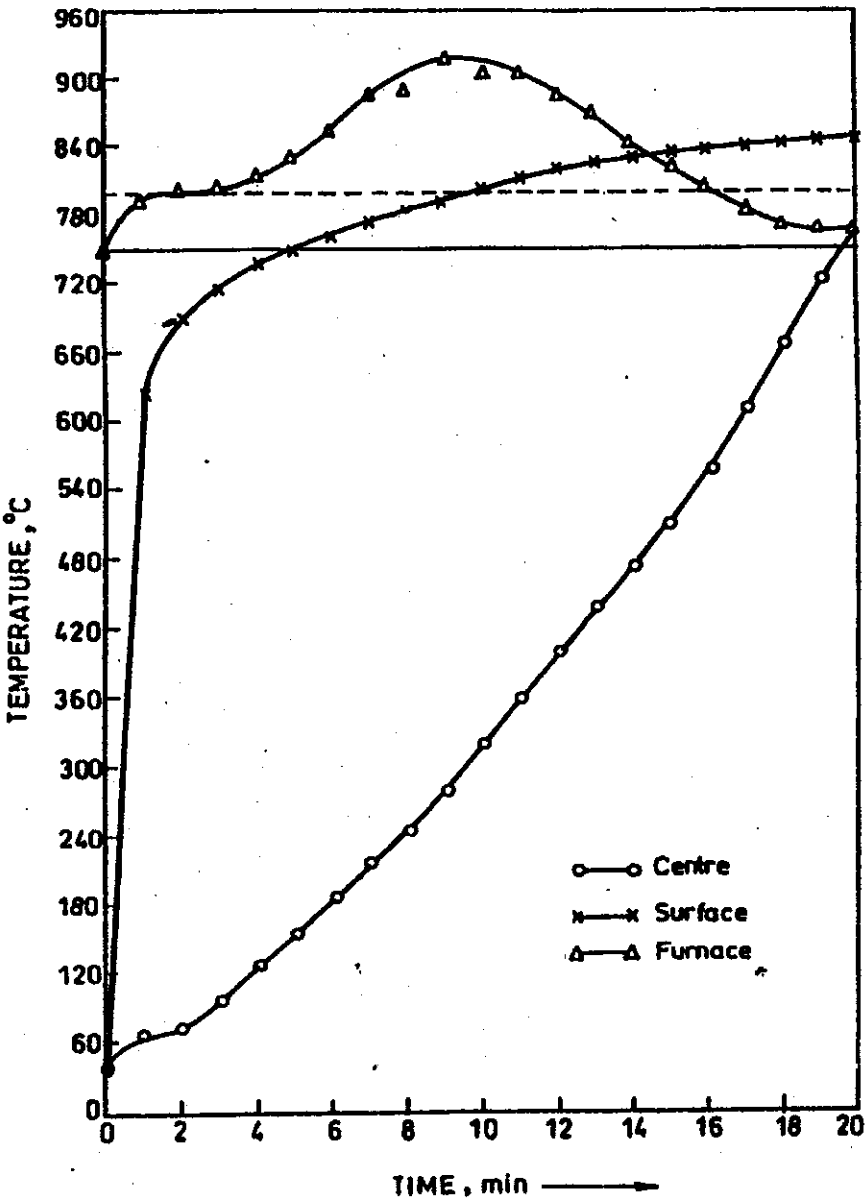

Figure 1. Non-combustibility of RMP sheet.

Average of the maximum temperatures for furnace, Specimen center and Specimen surface were found to be 915°C, 761°C and 849°C, respectively. The average rise in furnace temperature was 166°C while that for Specimen center was 12°C and that for Specimen surface was 100°C.

Since the rise in temperature during the evaluations for the non-combustibility on RMP specimens was greater than 50°C. Also the average mass loss of the specimens was 58% and the average duration of sustained flaming was 1094 s, which are higher than the limits specified for non-combustible material. Therefore the RMP was classified as a "*Combustible*" material.

TABLE 2
Fire Performance Evaluation Test Results for Non-Combustibility of RMP Sheets (3 mm, 2330 Kg/m³)

Test Results	RMP	Average Limits for Non-Combustible Material
Furnace temperature (initial)	749°C	—
Furnace temperature (max.)	915°C	—
Specimen center temperature (max.)	761°C	...
Specimen surface temperature (max.)	849°C	
	Maximum Temperature Rise (observed)	
Furnace temperature	166°C	50°C
Specimen center temperature	12°C	50°C
Specimen surface temperature	100°C	50°C
Mass Loss	58%	50%
Duration of sustained flaming	1094 s	20 s
Classification	Combustible	

Performance Evaluation for Ignitability

Since ignition is the initiation of combustion, the purpose of Ignitability Test is to determine the ease with which a combustible material can be ignited by a small heat source. Mainly two standard test methods are available for performance evaluation of materials. They are as per the British standard BS 476 Part 5 [8] and the International Standardization Organization (ISO 5657) [9].

Standard Test

In accordance with the British standard, BS 476: Part 5: 1968, a specimen of 228 mm × 228 mm × 3 mm is exposed to small flame for 10 s. A note is made of the extent of flaming during the application of the pilot flame and for 10 s immediately thereafter. The test helps to classify materials as "*X-Easily Ignitable*" or "*P-Not Easily Ignitable*" depending on whether on not a material flames beyond a specified distance in fixed time interval. This test enables hazardous materials to be separated from non-hazardous materials on the basis of their ease of ignition. Materials, which fail this test, should not be used in any exposed situation as they could easily lead to the initiation of a fire.

Performance

When sheets of 3 mm thick (2330 Kg/m³) were subjected to the test conditions no flaming was observed during the ignitability test duration. Thus the said RMP specimen were classified as 'P'-Not Easily Ignitable.

Assessment of Fire Propagation Index

The fire propagation index is a comparative measure of contribution to the growth of fire of a combustible material inside the building. The contribution to the fire in terms of heat contribution by the material can be assessed by various methods the prominent among them being the cone calorimeter and the British Standard method [10]. The higher the heat contribution by the material (fire propagation index), greater is the influence of the product on accelerating the growth of a fire.

Standard Test

The fire propagation index of RMP was determined using the fire propagation test apparatus and the procedure specified in British Standard BS: 476: Part 6: 1981. The test apparatus comprise of a HOT BOX made of asbestos wood. One side of the box contains the specimen while the opposite side has an opening provided for pilot ignition of the specimen and a window for observations. The combination of electric heaters and a series of small flames are used to create the standard fire conditions. Temperature of the resulting combustion products is measured using a chimney and cowl arrangement. The time-temperature curve thus obtained is used for calculation of the Fire Propagation Index.

A calibration run was conducted by exposing a standard non-combustible board of specified properties to the 14 jets of a gas pipe burner at a distance of 3 mm. The two electric heating elements with a total output of 1800 W were switched on after 2 min and maintained constant till the end of the test. The flue gas temperature was measured by two thermocouples inserted in annular space between chimney and cowl. Subsequently experimental runs were conducted with the specimen of RMP sheets keeping the test conditions same as that for calibration run. The time-temperature data was recorded and the fire-propagation index computed, as follows:

$$I = i_1 + i_2 + i_3$$

where i_1, i_2, and i_3 are the three sub indices computed from the time-temperature data

Performance

The three sub indices for the RMP sheet thus exposed were calculated to be $i_1 = 7.250$, $i_2 = 10.502$ and $i_3 = 2.738$ Thus the Fire Performance Index was $I = 7.250 + 10.502 + 2.738 = 20.49 \sim 20.5$ Therefore, the value of Fire Propagation Index—I, for the RMP was computed as 20.5 The time–temperature curves obtained during experimental investigations for calibration run and that for the specimens of RMP sheet are shown in Figure 2.

Surface Spread of Flame Classification

Combustible lining materials, once ignited, can permit spread of flame over the surface, thereby endangering materials at a distance from the initial outbreak. The surface spread of flame classification is determined by assessing this tendency of material to allow flames to spread over the surface. Material in higher class, as indicated by the numeral, are considered to spread flames more rapidly than these in lower classes. The commonly used standard methods for determination of flame spread are the Steiner Tunnel Method (ASTM E 84) [11] and the British Standard Method [12].

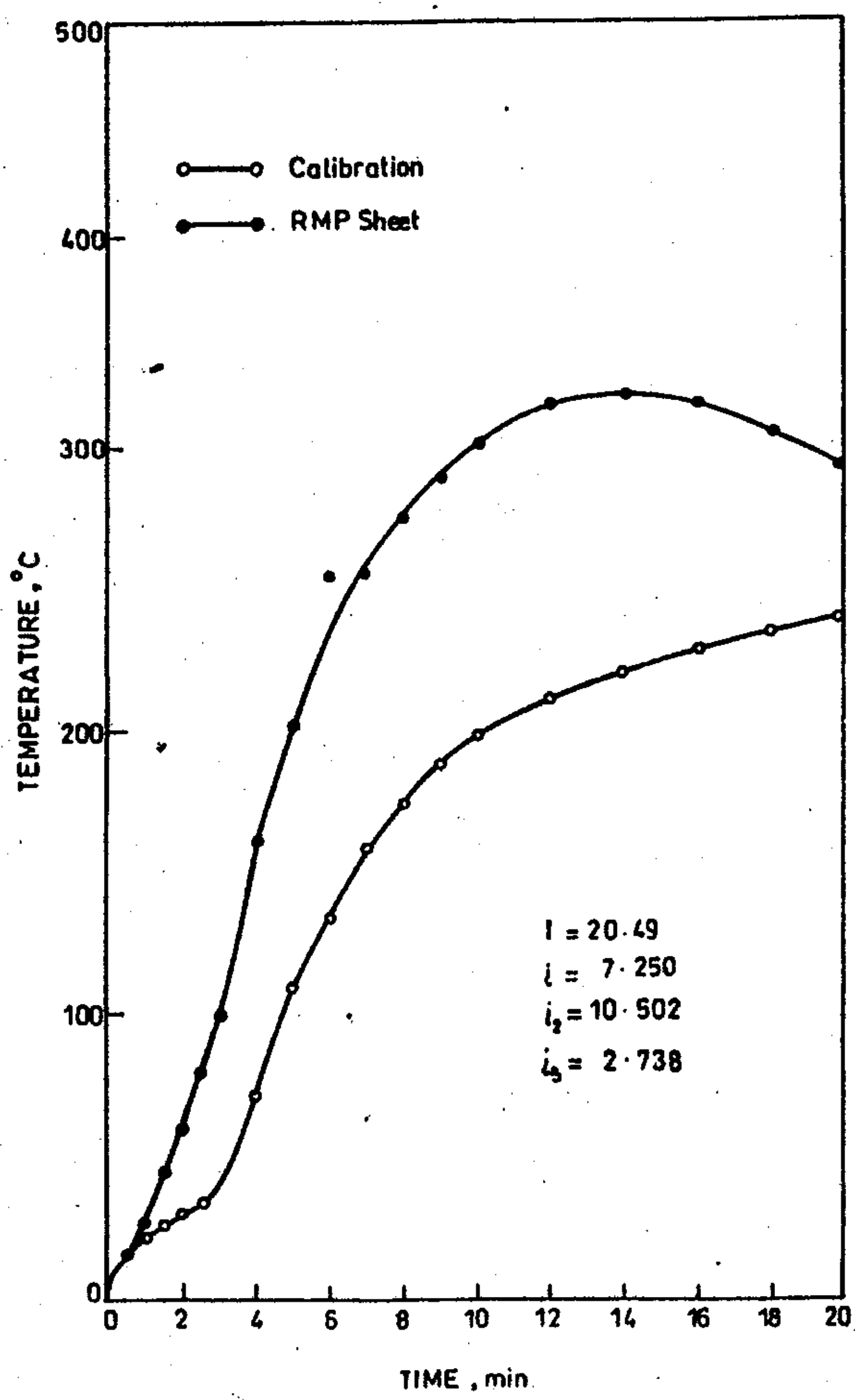

Figure 2. Fire propagation studies on RMP sheet.

Standard Test

The classification of surface spread of flame of RMP was determined using the apparatus and the procedure specified in British Standard, BS: 476: Part 7: 1987. The apparatus comprise of a 0.9 M×0.9 M gas fired radiant panel. Specimens are mounted in non-combustible holders and exposed to test conditions at right angle to the radiant panel.

The radiation intensity of the panel is maintained so as to impart a specific amount of radiation along the length of the specimen in accordance with the standard specifications. A pilot flame is used for the first one minute to ignite any combustible product being evolved from the surface of the specimen. The specimens are classified in accordance with the following criterion:

Class 1	165±25 mm in 1.5 min	165±25 mm in 10 min
Class 2	215±25 mm in 1.5 min	455±45 mm in 10 min
Class 3	265±25 mm in 1.5 min	710±75 mm in 10 min
Class 4	exceeding Class 3 limits	

Performance

Specimens of RMP were exposed to the radiant panel and as per the standard test conditions for the full duration of ten minutes. The average values of flame spread at 1.5 min. and the final flame spread (at 10 min) were 195 and 385 mm respectively (Figure 3). The specimens were classified in accordance with the above criterion and it was established that the RMP sheets subjected to the above test were of Class 2.

Smoke Generation

Smoke results from incomplete combustion of combustible lining materials used in the interior of a building. It posses danger to human life, particularly in the initial phases of a fire due to the loss of orientation caused by light obscuration. This can lead to panic and irrational behavior, which makes escape difficult with possibly fatal results. Smoke also hinders the fire fighting operations often making it impossible to rescue victims and to locate and effectively fight the seat of the fire.

Standard Test

Smoke generation from a material can be measured by a large number of test methods [13]. However, the Smoke Chamber method as per ASTM specifications [14] is the one most widely used and referred to in the literature. The apparatus essentially consists of an air tight chamber having provisions for mounting and exposing the test specimen to test conditions. Specimens can be subjected to smoldering as well as flaming conditions. Smoke thus generated by the specimen of a lining material is allowed to accumulate within the test chamber and the resulting attenuation of a light beam is measured using a photometeric system. Results are expressed in terms of maximum specific optical density. No classifications or criterion have been laid down in the standard specification, however, the higher the maximum specific optical density of smoke generated by a lining material, the greater is it's influence in reducing visibility.

Performance

The specific optical density of smoke generated by the specimen of RMP was determined using the smoke density chamber. During the test, the specimens were exposed both to the Smoldering/Non-Flaming exposure condition (radiant heat only) and to the Flaming condition (radiant heat along with flames). During both the exposures, the smoke generated by the specimens was allowed to accumulate inside the smoke chamber and the percentage transmittance across a light path was measured. Maximum Specific Optical

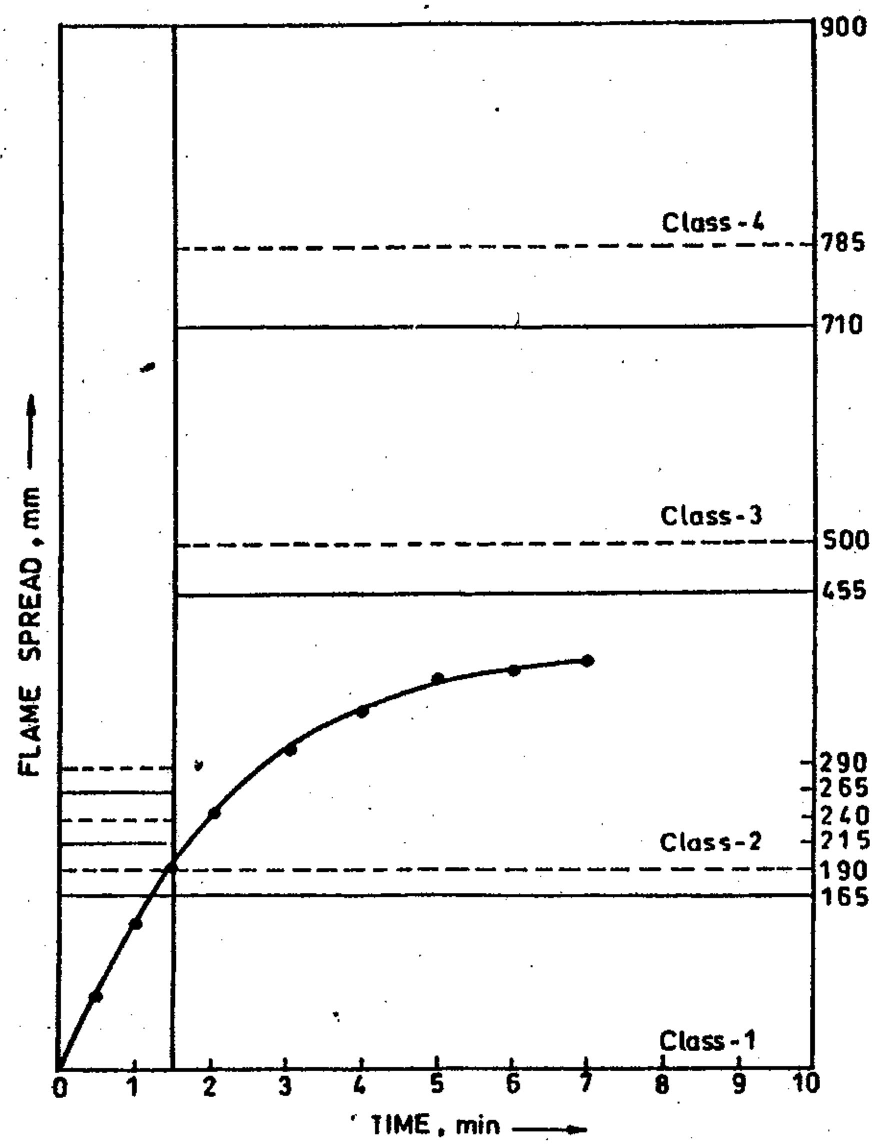

Figure 3. Surface spread of flame classification of RMP sheet.

Density D_{max} was computed using transmittance at different time intervals (Figure 4). The computed mean of D_{max} generated by the different specimens of RMP under flaming and non-flaming exposure modes were 532 and 470, respectively.

Limiting Oxygen Index

The minimum concentration of oxygen in a mixture of oxygen and nitrogen flowing upwards in a test column that will just support combustion is determined under equilibrium conditions of a candle like burning. The equilibrium is established by the reaction between the heat generated from the combustion of the test specimen and the heat lost to the surroundings. The limiting value thus obtained is known as the Limiting Oxygen Index (ASTM D 2863) [15] of the material.

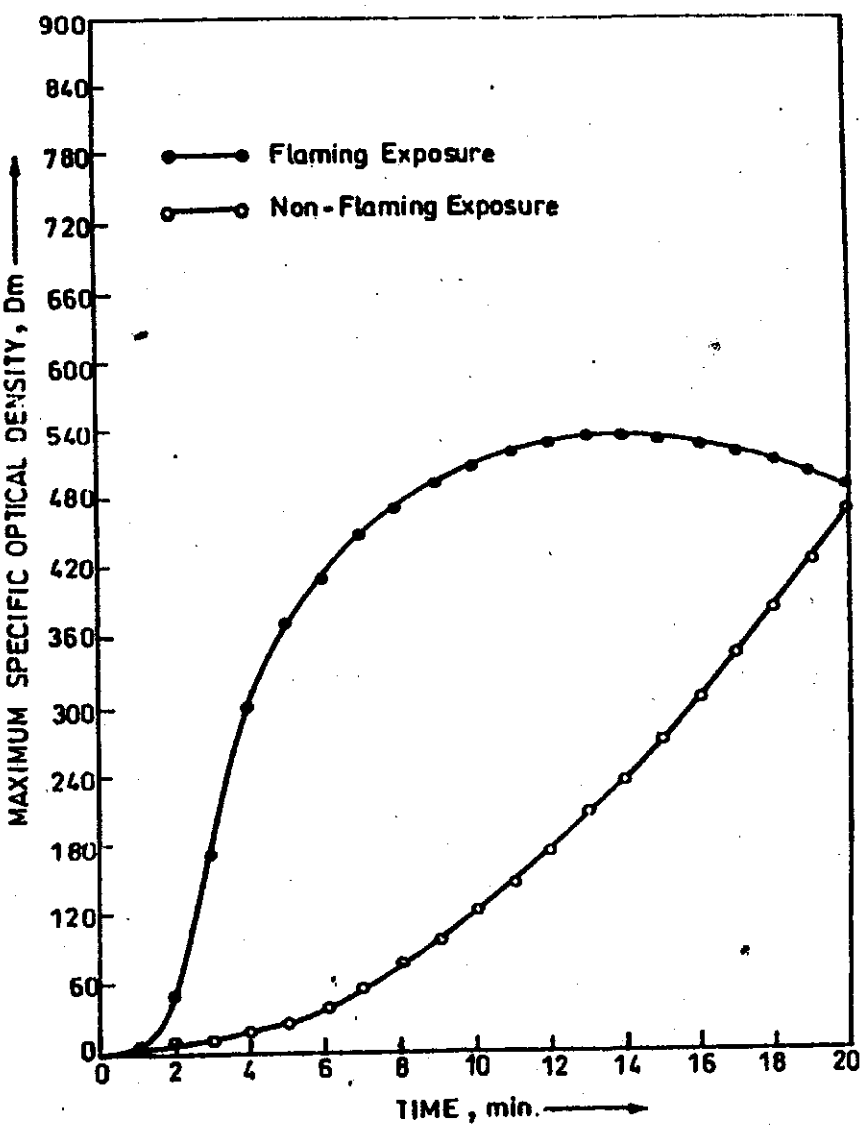

Figure 4. Smoke generation from RMP sheet.

Standard Test

The apparatus consists essentially of a heat resistant glass column of 95 mm ID and 305 mm height. The top of the column is reduced to 50 mm ID. The column is placed inside a mount, which has a provision for mixing and uniform distribution of the gases entering at the base of the column. An oxygen analyzer is used to measure the oxygen concentration in the mixture flowing through the glass column. Suitable flow control and measurement devices are used to monitor the volumetric flow of gases into the column. The equilibrium condition is measured by one of the two arbitrary criteria namely:

1. a period of burning, or
2. a length of test specimen burnt.

TABLE 3
Evaluation of Limiting Oxygen Index (as per ASTM D 2864)

	Burning	
Oxygen, %	Duration, s	Length, mm
44.9	180+	32
43.3	180+	28
41.1	180+	25
38.0	133	05
37.5	020	01
37.8	075	04
38.1	**180+**	**22**
38.2	180+	22
	LOI = 38.1	

The equilibrium is approached from both sides of the critical oxygen concentration in order to establish the oxygen index, which is calculated as follows:

$$\mathrm{LOI} = 100[V_0/(V_0 + V_n)]$$

Where, V_0 is the volumetric flow of oxygen, cc/s, and V_n is the corresponding volumetric flow rate of nitrogen, cc/s

Performance

A 'U' type clamp with graduations on one side was used in the present study. A tentative initial oxygen concentration was selected (around 45%) to start the set of experiments. The entire top of the specimen was ignited and the duration of specimen burning, if any recorded. The specimen was found to burn with a sustained candle like flame for different duration and lengths at different oxygen concentrations (Table 3). The specimen was found to burn freely to meet the test criteria at 38.1%. Thus LOI for the present sample was 38.1.

Results and Discussion

One of the main applications of RMP sheets is roofing. Traditionally, timber, steel or asbestos is used for this purpose. While timber is now available in limited quantities, steel and asbestos require relatively higher energy for processing. Also, asbestos is banned in many countries on account of associated health hazards. Thus RPM is an alternate material that can take care of the shortfall in traditional building materials. RMP sheets were found to be combustible though not easily ignitable, which is at par with wood and many polymeric materials. The fire propagation indices, i_1 and I were found to be 7.2 and 20.5 respectively. It was also found to be having low surface spread of flame

TABLE 4
Fire Performance Characteristics of Wood & Alternate Building Materials [16]

Material	Thickness mm	Density Kg/m³	Non-Combustability	Ignitability	Fire Propagation Index		Surface Spread of Flame Class	Smoke Density	
					I	i_1		Flaming D_m	Non Flaming D_m
Kail Wood	12	495	C	P	16.1	41.5	4	228	329
Particle Board	12	400	C	P	14.3	36.2	3	261	410
Fibre Board	12	235	C	P	33.4	56.7	4	218	308
Plywood	3	715	C	P	18.6	36.5	4	74	162
PVC Sheet	2	1490	C	P	8.1	20.6	4	610	186
RMP Sheet	2	2230	C	P	7.2	20.5	2	532	470

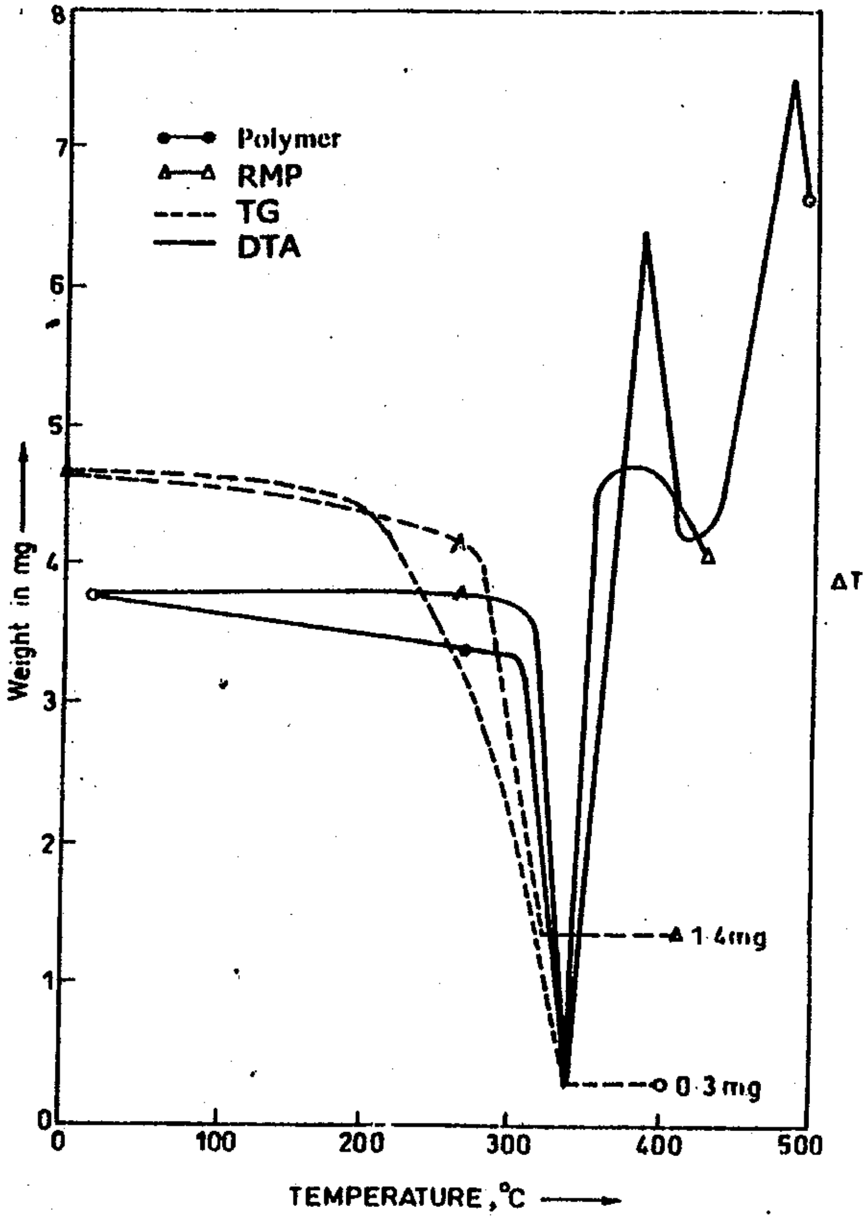

Figure 5. Thermal analysis of RMP.

rate and thus classified as Class 2 according to the BS 476 Part 7. Smoke generation evaluated in accordance with ASTM E 662 was found to be relatively lower for a plas sheet (Table 4). The limiting oxygen index was found to be 38.1 indicating the mater to have fairly good flame resistance.

When compared with some other building materials [16] used for applications simi to those of RMP sheets, e.g., flooring, paneling etc., it was evident that RMP is relatively better material in terms of fire safety (Table 4). PVC sheets show a higl fire propagation index and are classified as having "Class 4" surface spread of fla rating—Class 4 is the worst rating for a given material. Also, the smoke generation w found to be higher during the flaming combustion mode. Plywood, also of equal thickn

(3 mm) exhibit significantly higher fire propagation index ($i_1 = 18.56$, $I = 36.52$) and a poor surface spread of flame grading (Class 4). The smoke generation was lower but that is to be expected when you compare a plastic with a cellulosic material. Similar was the phenomenon when the material was wood (Kail wood, 12 mm, 495 kg/m^3). A higher fire propagation index (16.1 and 41.5) poor surface spread (Class 4) and relatively lower smoke generation was observed.

The above clearly indicates that RMP sheets exhibit better fire performance as compared to the conventional building materials. The claim that fire performance of a polymeric material is improved by using red mud as a filler material can be further substantiated by thermal studies on the modified polymer. Red mud was used, in 1:1 ratio, to modify the polymer (Polyester resin). Sheets were prepared by using suitable hardner and accelerator. Differential thermal analysis (DTA) studies exhibit absence of exothermic peak while the Thermo gravimetric (TG) curves revels a comparatively lower weight loss in case of specimens modified by red mud (Figure 5). Thereby clearly indicating that red mud has played an important role in the improvement of thermal properties of the polymer.

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