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-EXPERIMENTAL INVESTIGATION ON THE BURNING CHARACTERISTICS OF THICK SOLID - POLY METHYL METHACRYLATE (PMMA)

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ABSTRACT: Fire safety process poses several challenges due to lack of understanding of the controlling mechanisms present in different and difficult situations. The primary importance is on the flame spread studies and has been carried out by many researchers. Extensive studies have been made by researchers on planar and non planar surfaces using PMMA to identify the influencing parameters that affect the flame characteristics and flame spread. Both planar and non-planar surfaces of PMMA find its application in modern buildings and in solid motors. In view to the architectural advancements, it is essential to understand the different scenarios of flame spread over planar and non-planar surfaces. This study aims at carrying out a parametric study to understand the burning characteristics of thick solid PMMA of different thickness, orientation, and flame spread direction on planar and non planar surfaces. PMMA has been chosen due its homogeneous and non-charring nature. A comprehensive experimental study has been carried out to understand the nature of burning of planar and non-planar PMMA surfaces. This has been accomplished by using transparent PMMA blocks of thickness 10mm, 20 mm, 30 mm and height 300mm with and without steps. The PMMA samples were burnt differently to study the thickness, orientation and plane effect on the burning characteristics. Direct flame images and videos were captured using two DSLR cameras one in the front and another viewing from the side. The PMMA sample along with the holder was kept on a weighing machine and the mass loss and its rate was monitored at an interval of 2 minutes. The flame temperature was measured using k – type thermocouple. The results show that, the upward flame spread for all cases are accelerating due to the convective buoyancy effect. However, with increase in the sample volume, the pyrolysing zone height increases. Also, the mass loss rate is found to be influenced by the radiation loss from the flame. More the radiation loss less will be the heat given to the virgin fuel. The upward flame spread cases showed boundary layer flame with a short or moderately longer premixed blue zone for all the cases. However, in horizontal orientation, the flame spread was interestingly different with the initial anchor didn't move until the flame spreads over the entire surface. In horizontal case, the flame is a boundary layer flame only for a short span and then it became more like a turbulent flame. Solid to vapour bubble growth was found to be more intense in horizontal cases with many flamelets getting generated and collapsed. In non planar stepped samples, the mass loss rate is found to be more because of secondary flames at the wake zone in the vicinity of steps. The step enhances the air entrainment forming blue premixed zone near the steps leading to maximum mass loss.

KEYWORDS: Planar, Non planar, Radiation, Buoyancy effect, Pyrolysing.

I. INTRODUCTION

Polymer materials widely used in all areas in construction industry, in transport, in people's household and in decorative purposes, engineering polymer is used as a replacement material for the woods and metals. Among the seven classifications of plastics, PMMA is one of the non-reusable and recycled plastics. It is a not readily biodegradable plastic. PMMA is used as a substitute for transparent glass in windows, aquariums and hockey rinks and used in medical technology as implants, dentistry .The PMMA is also used as artistic and aesthetics usages. Most of the organic polymers while undergoing combustion process have varied burning characteristics in which Poly Methyl Methacrylate (PMMA) is a non charring solid fuel compared to the coal. The

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PMMA has a slow burning characteristic among the other polymers. Moreover, the synthetic polymer is easier to handle, process,and less expensive than polycarbonate. In practice, PMMA is often used for craniofacial tissue defects such as skin and dentures .PMMA has great mechanical properties and low toxicity. While being popular for hip-joint transplantations. Most of the organic polymer upon burning produce the toxic gases such us carbon monoxides, Nitrogen oxide, Sulphur oxides, and carbon dioxides which are harmful to human beings and also causes poor visibility. To minimize these hazards fire behaviour of the materials are assessed. Poly Methyl Methacrylate (PMMA) is a transparent material which has a light transmission of about 92%. Besides that it also has a excellent corrosion4 resistance and shatter resistance property. These also make it as a popular and widely used in the building industry and general consumer's product market. Poly Methyl Methacrylate is a combustible material which will be softened or melted upon heating. So its fire behaviour would also be analyzed while using it as a fuel. increase in the usage of polymers as decorative material and replacement for glasses in the construction and industries so in case of fire hazardous situation the fire is uncontrollable while burning the PMMA the flame spread rapidly over the PMMA surfaces and it burns for a long duration and the melted PMMA at high temperatures drips over the other combustibles, so it causes severe damages to property and for the people. Therefore it is important to study the flame characteristics of the PMMA for the safety aspect. PMMA, short for Poly Methyl Methacrylate and also known as acrylic (glass) or plexiglas, is a thermoplastic often used as an alternative to glass due to its transparency, its light weight and it is shatter-resistant.

II. LITERATURE REVIEW

The Poly Methyl Methacrylate (PMMA) is a synthetic resin produced by polymerization of monomer Methyl Methacrylate (MMA). It is used as a fuel in the hybrid rocket engines and many researchers believed that it is used as a fuel for future. so that we're looking forward to analyse experimentally to study about the thick solid fuel (PMMA) behaviour while burning and to understand the factors which are influence while burning the thick solid fuel PMMA. The propagation of diffusion flame over the solid fuel surface is regarded as the basic process in the fire initiation and fire growth .There are two types of flame spread which is upward flame spread and downward flame spread propagations. So we have collected a various papers which involve the study of mechanism of flame spread over polymer (poly methyl methacrylate) of different configurations. From those papers we gained some information on the burning behaviour in poly methyl methacrylate (PMMA) and how they are affected by important factors such as the pressure condition, orientation, changes in sample dimensions etc. The Mass Loss Rate, which is an important characteristic in terms of using any solid fuel because it determines the fuel economy, requirement of fuel. The fuel mass loss rate refers to the rate at which a condensed-phase fuel is decomposed to gases due to the energy transferred from its surrounding heat sources such as flames, hot gas, and enclosure walls.8 Increasing the width and thickness of sample increases the area exposed to the fire which in turn increases the mass loss rate of samples [1] done the experiment for horizontal flame spread observed this trend [2] also observed the same effects for the downward flame spread and they also relate the results with the mathematical models by the pyrolysis kinetics. [3] Expressed the similar trend also for upward flame spread and they found that mass loss rate of the sealed sides of samples is lower than the unsealed cases. Then for the experiment with orientation of samples, the mass loss rate were increased with the increase in fuel inclination angle because the convective heat flux to the solid surfaces increases with decrease in the radiant heat flux to the solid surface which was observed [4] and they also conduct the experiment at different pressure environments found that the mass loss rate increases exponentially with increase in the pressure. When the thermal conductivity of the material to be assessed is large, heat transfer from the flame to the solid would be transported so efficiently. Therefore the temperature on the solid surface increases leads to increase in flame spread rate . For the thicker cases, the flame spread rate is increased by the increasing gas flow velocity due to the thinning boundary layer a larger amount of heat flux will be radiated from the flame to the fuel. For the opposed flow having low concentration of oxygen but having high gas velocity leads

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to decrease in the flame spread rate, as the flow velocity increases the length of heat conduction through the gas decreases due to the thin boundary layer the flame moves closer to the fuel surface this reduction of the length of heat conduction from flame to fuel could decrease the heat flux due to convective effects.In upward flame spread the flame is initially laminar condition the after sometime it converts into turbulent flame. In the laminar condition the heat is transfer from to the flame to the fuel is by the convection mode . For the low oxygen concentration the flame spread rate decreases with increases in gravity because the flame will propagate only if there is a sufficient amount of oxygen concentration level. . When the gravity is increased the flame spread rate is decreased until no flame propagation occurs for the thin samples. As the pressure is decreased the flame spread rate is decreased[7], because the pressure has a direct influence in the buoyancy level through the variations of density so the pressure is similar to that of the effects of gravity

III.METHODOLOGY

The experimental study were conducted on PMMA samples of thickness 10mm, 20mm and 30 mm. with a sample height 300 mm and width 50 mm. The schematic of the experimental setup is shown in the following figure. The PMMA slabs were tightly mounted on a wooden board inserted in an aluminium holder. The wooden plate has a slot in it and the slab can be tightly placed in it and shielded using aluminium foil. All the edges are covered with aluminium foil that prevents the wooden plate catching fire. Upon ignition, the flame spreads over the exposed surface and steady burning can be attained. Experimental apparatus was carefully placed at the centre of the cabin to avoid asymmetric entrainment. The whole setup is placed in the dark room in order to get better flame geometry and the room should be closed to protect flame from external disturbance.

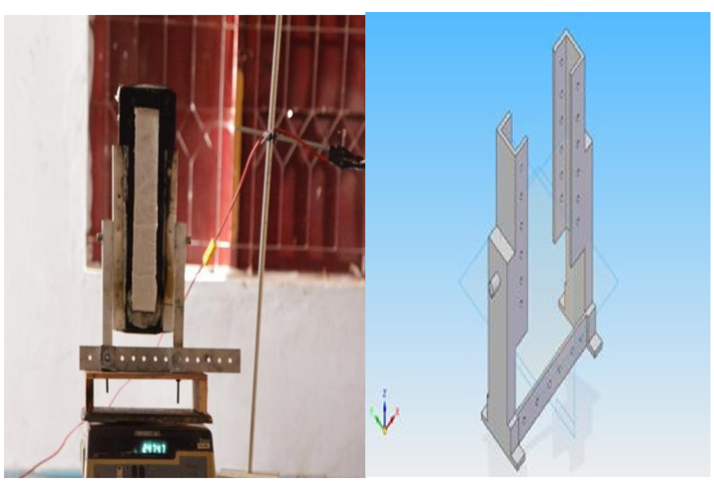

Figure 1 PMMA slab holder

IV. EXPERIMENTAL RESULTS

The experiment was carried on thermally thick PMMA samples of various thickness was done for upward and downward flame spread then have found out the mass loss rate, flame height, flame width, flame pattern along with temperature distributions on surface over the PMMA. The effects on PMMA samples for the upward flame spread in which the mass loss rate increases rapidly compared to the downward flame spread because of the increase in the flame contact area and flame buoyancy which tends the upward flame to propagate faster these were the reasons for the increase in mass loss rate. It was shown with the help of below

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diagram. It is difficult to determine the location of the flame tip because of the fluctuation of the flame while burning. So the data such as the flame height and flame width we are provided were only approximate. Mass loss rate for the (one-third of its length, half of its original length) stepped sample upward and downward flame propagation was observed by this we have found that there is no significant changes for the upward flame between the two different stepped portion of the sample. It is difficult to determine the location of the flame tip because of the fluctuation of the flame while burning. So the data such as the flame height and flame width we are provided were only approximate. We have found the results on the flame height and flame width when it reaches the maximum rate. For the inclined cases with respect to the vertical plane the flame height decreases at an inclination of 45 0 for the upward and downward flame propagation which is same for the inclination with respect to the horizontal planes which is in agreement with the results of [5]. The stepped cases, as the flame height is directly proportional to the flame spread rate, the flame spread rate is maximum for the least stepped portion stated in the here in this the flame height reaches the maximum value with respect to what type of the flame propagation is experimented[8]. We have found the result for the horizontal flame in the lateral and frontal flame propagation, the flame height maximum for the frontal flame because it have more pyrolysis region when compared to the lateral flame spread . For the vertical cases, increasing the thickness for the downward flame spread the flame height decreases which are also same for the upward flame propagation because when increasing the thickness the time taken to propagate the flame over the sample was more. As the flame width is depend on the sample length. The flame width for the vertical cases of 20mm it is more for the upward than the downward flame whereas in the other two types of samples 10mm and 30mm the flame width is low for the upward than the downward flame. In the inclination of 45 ^{0} with respect to the vertical plane and horizontal plane the flame width is too low for the downward flame when compared to the upward flame this shows that even though the buoyancy leads the flame to propagate the inclination has a dominant role. In stepped sample, the flame width increases when it reaches the stepped sample and the flame width is decreased with decrease in the step size which is contradict to results. [6] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased. In the horizontal experiment the flame width is higher for the frontal flame propagation than the lateral flame due to the buoyancy effects.

For all the vertical upward flame propagation, the flame was initially laminar but after sometimes it transitioned into the turbulent flame so the flame becomes more vigorous. For the downward flame propagation the flame starts burning in the lateral sides of the sample forming an inverted 'V' shaped flame pattern and it propagates slower when compared to the upward flame because in the downward flame the flame propagates in the opposite direction of the gas flow velocity. Especially in the stepped samples, there is two pyrolysis region one at the starting point and another one anchors at the stepped portion. In the downward propagation the flame when entering in the stepped portion the flame first engulfed the stepped edge and again it catches the inverted 'V' shape by anchoring the lateral sides of the stepped region[7]. Then for the horizontal propagation and for its inclined cases, the blue flame (ie, the pyrolysis region) is more than the vertical flame propagation. In the inclined cases, the horizontal plane inclination,the flame propagation is faster than the vertical plane inclinations.

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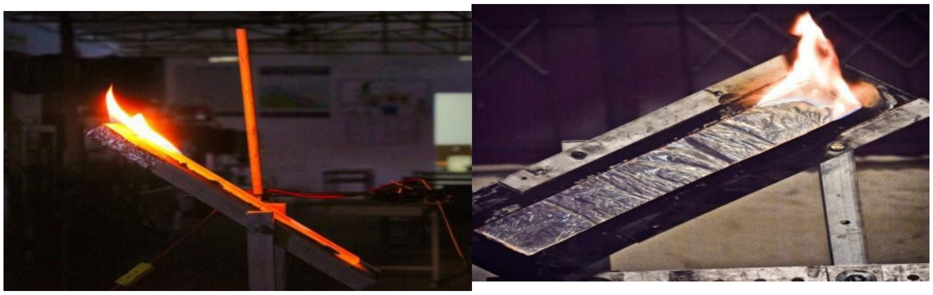
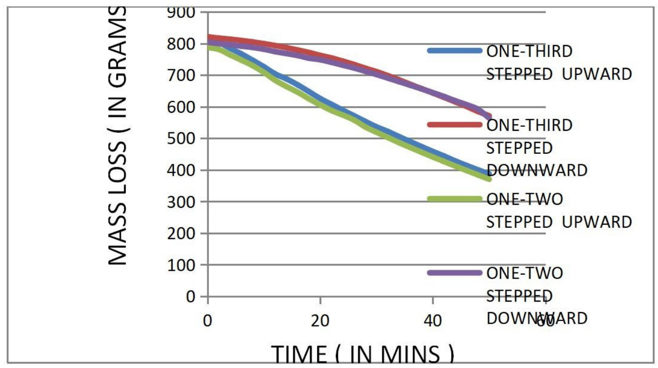


Figure 2 PMMA slab burning in angular orientation

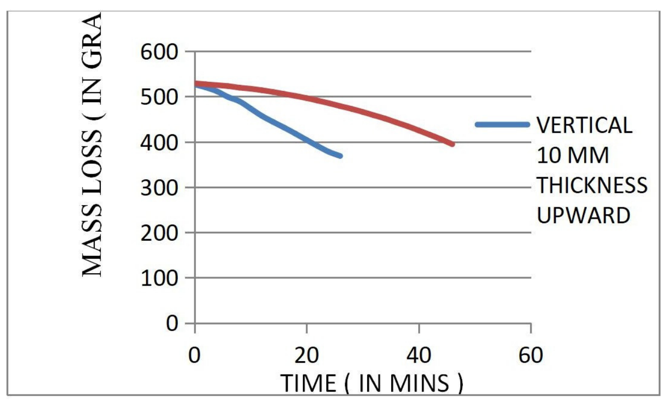
Mass loss rate in stepped slab

	MASS LOSS (IN PERCENTAGE)			
Time (mins)	ONE-THIRD STEPPED	ONE-THIRD STEPPED	ONE-TWO STEPPED	ONE-TWO STEPPED
	UPWARD	DOWNWARD	UPWARD	DOWNWARD
10	11.31	2.66	10.04	2.76
20	23.59	7.18	23.08	6.89
30	34.52	13.45	34.08	12.71
40	44.1	21.66	44.01	19.85
50	52.71	30.44	52.95	30.38



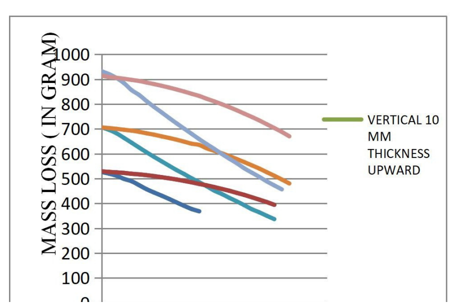
Mass loss rate in vertical burning

MASS LOSS(IN PERCENTAGE)			
Time (mins)	10 mm thickness	20 mm thickness	30 mm thickness
10	10.06	11.53	10.26
20	23.27	24.37	22.54
30	34	36.05	33.5
40		46.63	43.77



Mass loss rate in vertical burning at different thickness with upward and downward

MASS LOSS(IN PERCENTAGE)			
Time (mins)	10 mm thickness	20 mm thickness	30 mm thickness
10	2.28	2.5	2.35
20	6.19	7	6.11



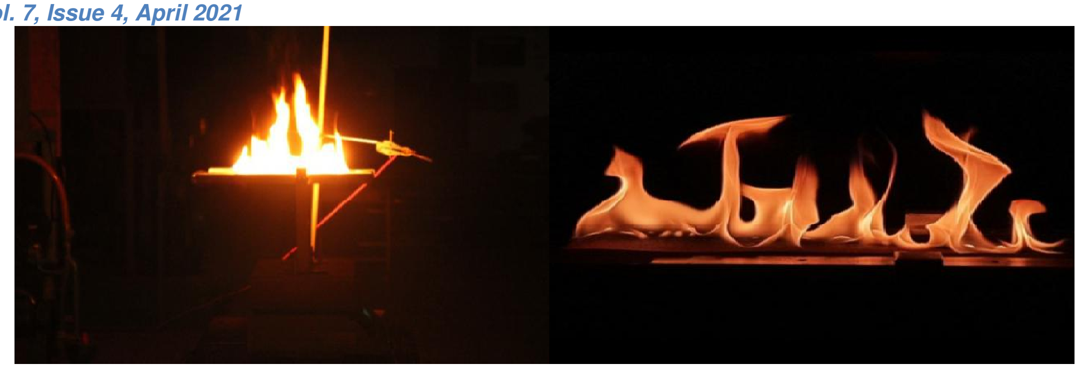


Figure 3 Horizontal flame spread – Lateral

Figure 4 Horizontal flame spread – Longitudinal

Figure 5 Vertical flame spread

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Figure 6 Stepped burning

CONCLUSION

The results show that, the upward flame spread for all cases are accelerating due to the convective buoyancy effect. However, with increase in the sample volume, the pyrolysing zone height increases. Also, the mass loss rate is found to be influenced by the radiation loss from the flame. More the radiation loss less will be the heat given to the virgin fuel. The upward flame spread cases showed boundary layer flame with a short or moderately longer premixed blue zone for all the cases. However, in horizontal orientation, the flame spread was interestingly different with the initial anchor didn't move until the flame spreads over the entire surface. In horizontal case, the flame is a boundary layer flame only for a short span and then it became more like a turbulent flame. Solid to vapour bubble growth was found to be more intense in horizontal cases with many flamelets getting generated and collapsed. In non planar stepped samples, the mass loss rate is found to be more because of secondary flames at the wake zone in the vicinity of steps. The step enhances the air entrainment forming blue premixed zone near the steps leading to maximum mass loss.

FUTURE SCOPE

The present study can be extended in the future by considering more influencing parameters with additional diagnostic tools like Schlieran, Shadowgraphy and other flow visualization techniques.

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