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Development of Flexible Polyurethane Nanocomposite Foam with Enhanced Flame Retardancy

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ABSTRACT
Polyurethane (PU) is a versatile polymer fluid finds application in foams, coatings and adhesives etc. The high level inflammability of PU foam leads to fire related accidents. The broad applications has lead to the present investigation concerning about the development of flexible polyurethane foam (FPUF) with enhanced flame retardancy. The effect of addition of melamine cyanurate flame retardant (MCFR) and organically modified **montmorillonite** *(OMMT) clay was investigated in the present study. The developed PU foam was tested and compared with unmodified PU foam (control), for its flame characteristics, physical (foam density, cell structure), mechanical (tensile strength, rebound resilience) and thermal properties. The developed PU foam shows UL-94 flame rating of V-0 and V-1. The present investigation confirms the developed flexible polyurethane nanocomposite foam with improved flame retardant characteristics.*

Keywords: *Flexible polyurethane foam, Flame retardant, Nanofillers, Nanocomposite foams*

1. INTRODUCTION

Flexible polyurethane foams (FPUF) have found a wide variety of applications in domestic and industry as well. It is most commonly used in cushioning purpose in furniture and vehicle manufacturing industries etc. The demand of FPUFs has been increasing due to their remarkable combination of properties such as less weight and ease of manufacturing. The major production of FPUF was carried out based on the urethane materials [1]. Polyurethane foams developed may be either an open or closed cell structures. The structure mainly depends upon its chemical compositions. FPUF normally contains open cell structures. The structure of the foam allows air and moisture inside the foam. The microstructure of foam is fundamentally important in determining its bulk mechanical response [2].

The major drawback in FPUF is its inherited poor flame retardant (FR) characteristics. The quantity of combustible gases released is more in FPUF than flaming, which is a real threat in applications [3]. During combustion, FPUF produces toxic, dense smoke, which suffocates people [4]. Studies shows that almost one third of residential fires were originated from soft furnitures [5]. The addition of FR in polymer controls the inflammability of a material. Halogen containing and halogen free FR are used commercially to enhance the flame retardant characteristics. Of these, halogen free FRs are environmentally friendly and the usage has been increasing currently [6-7]. The FR incorporated in the polymer material forms a non-flammable char layer, providing a shield and barrier in the polymer against the flame. It also inhibits heat and oxygen transfer between the flame part and the underlying FPUF material [8]. In the present study, the effect of addition of MCFR and OMMT in FPUF was analyzed by flammability test, mechanical, physical and thermal properties.

2. EXPERIMENTAL

2.1. Materials

Polyol and isocyanate was obtained from Sriram foams, Chennai, India.

2.2. Optical Microscope

Optical microscope was employed to study the morphology of the prepared FPUF. The prepared FPUF cell structure was measured with 50 X magnification. The optical microscope used was CARLL ZEISS (AX10 ERC5s), Germany.

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2.3. Thermo Gravimetric Analysis (TGA)

TGA studies were carried out using EXSTAR6000 (TG/DTA), Japan to analyze the thermal stability, physical and chemical changes of the prepared FPUF with respect to increase in temperature. Sample of 5 mg was heated up to 800 ^{o}C at a heating rate of 20 ^{o}C per minute in nitrogen atmosphere (nitrogen flow rate 140 ml/min).

2.4. Tensile strength

Tensile strength was found using an universal testing machine (UTM) according to the standard IS 7888 [9]. The tests were performed on the prepared FPUF using UTM machine with a cross head speed of 500 mm/min as per the standard. The DAK system inc (SERIES 9000), India was used to measure the tensile strength.

2.5. UL - 94 Test

UL - 94 test was used to measure the flammability characteristic of the prepared FPUF. The UL - 94 vertical test were performed on an vertical burner with a burner flame height of 2 cm. The sample size used was 100 mm × 12.5mm × 3mm according to the standard [10].

2.6. Rebound Resilience

The impact resilience of FPUF was determined by resilience tester (Blue Steel Engineers PVT. LTD, India). A preferred amount of load is applied on the prepared FPUF to measure the absorbance of energy.

2.7. Foam Density

Density test were carried out according to ASTM D-1056 methods [11]. The density of prepared FPUF was calculated with respect to mass/volume ratio.

3. RESULTS AND DISCUSSION

3.1. Morphology

FUPF prepared was examined by optical microscope in order to determine its morphology. Fig.1 a shows that control FPUF was observed with open cellular structure. Disintegration in the cell structure was not observed. Fig.1 (b - f) shows the addition of various percentage of MCFR and OMMT in FUPF does not change the cell structure and homogeneous integration of FPUF with respect to the control. This may be due to the nano particle size of MCFR and OMMT which is present in the cell wall or backbone of polymeric matrix [12].

3.2. Density

The density variation with respect to the addition of various percentage of MCFR is shown in Fig. 2. .It was observed that the density increases with respect to the increase in various percentage of MCFR content. The similar trend was observed in the earlier studies [13]. The density of the FPUF with various percentage of MCFR was found to be higher than that of the control FPUF. Increase in the densities of FPUF samples may be due to the filled voids with respect to the addition of MCFR [14].

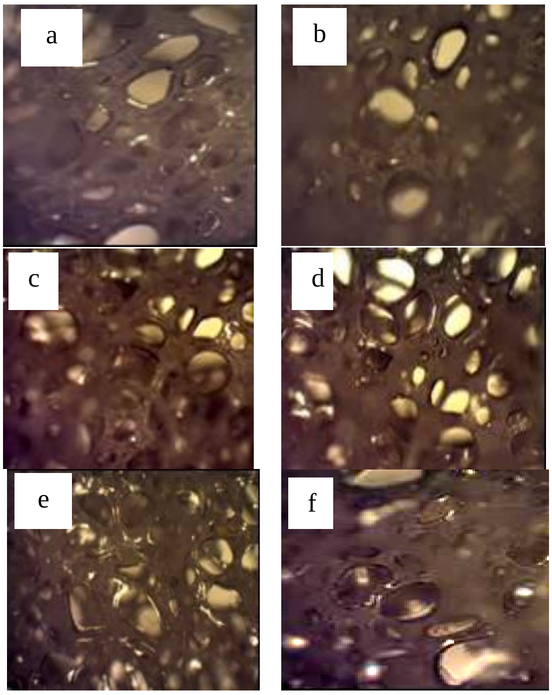

Figure 1 : Morphology of FPUF (a - Control, b – 1 % MCFR, c- 2 % MCFR, d- 3 % MCFR, e- 4 % MCFR, f - 1 % OMMT.

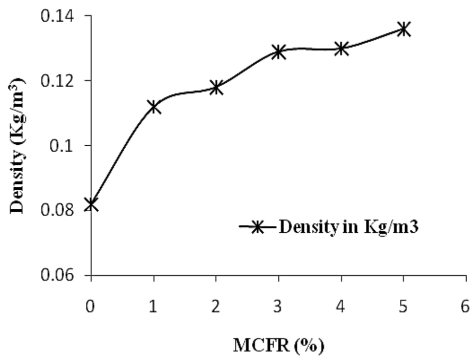

Figure 2: Density variation with respect to the different % of MCFR.

3.2. Flammability of FPUF

Table 1 shows the UL - 94 rating of the prepared FPUF sample. V - 0 (Best),V - 1 (Good) and V- 2 (Poor) are the different UL-94 rating which is used to find the flammability of FPUF. The duration of flaming for the control FPUF was found to be 50-55 seconds with a V-2 (Poor) UL - 94 rating. The addition of 1 % of MCFR and OMMT shows V-0 (Best) UL-94 rating with 6-8 secs and 8-10 secs respectively. The UL - 94 rating of FPUF with 2%, 3% and 4% MCFR was found to be V-1 (Good). From the UL - 94 rating test result it was found that increase in various percentage of MCFR and OMMT does not resulted with a UL-94 rating of V-0 (Best). The addition MCFR and OMMT flame retardant accelarates the char formation [15] and due to this the flammability duration is reduced or controlled than the FPUF control.

Table 1. UL - 94 rating flammability test.

Samples	Duration of flaming for each flame application **(sec)**	UL -94 rating
Control	50-55	Failed
MC 1%	**6-9**	**V - 0 (Best)**
MC 2%	15-17	V -1 (Good)
MC 3%	18-20	V -1 (Good)
MC 4%	20-23	V -1 (Good)
MC 5%	28-32	V- 2 (Poor)
OMMT 1%	**8-10**	**V- 1(Good)**
OMMT 2%	25-28	V - 2 (Poor)
OMMT 3%	28-32	V - 2 (Poor)

3.3 Mechanical properties – Tensile Strength and rebound resilience

Fig. 3 shows the change in the tensile strength with respect to the change in various % of MCFR. It was observed that MCFR content of 4% shows high tensile strength of 0.145 Mpa when compared with other % of FPUF. Decrease in tensile strength was observed with further increase to 5% of MCFR with the values 0.113 Mpa. Studies shows that distribution of FR may be not uniform because of the agglomeration of FR in FPUF. This leads to the non-uniform transfer of FR in FPUF which may be the one of the reason for the decrease in tensile strength [16]. Rebound resilience was found to be decreasing from 29 to 21.45 with the increase of MCFR from 1 % to 5 % respectively and this is shown Fig. 4.

3.4 Thermal properties of FPUF

TGA was performed to study the thermal properties of the prepared FPUF. It was found that the rate of weight loss for control FPUF is rapid and decomposes rapidly between 260°C and 320°C, corresponding to a weight loss of around 50% at 324°C. Fig. 5 shows the thermogram of MCFR and OMMT of 1 %. In case of 1 % MCFR, the thermogram shows two maximum peaks centered at 368.5°C and 537.5°C, indicating the two step decomposition reaction. The thermo gram of 1% of OMMT FPUF shows the decomposition involves between two maximum peaks at 377°C and at 550°C. Thus, it was observed that these two flame retardants can shift the decomposition temperature and increase the char formation. Studies shows that, when char residue yield is higher, the better the flame retardence [17].

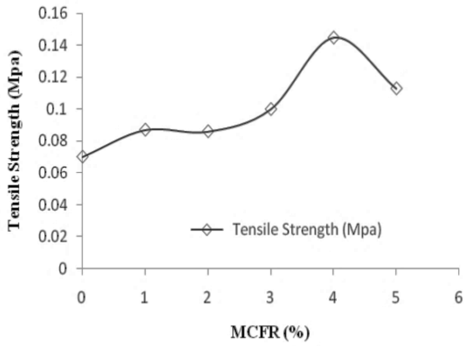

Figure 3: Tensile strength variation with respect to different % of MCFR.

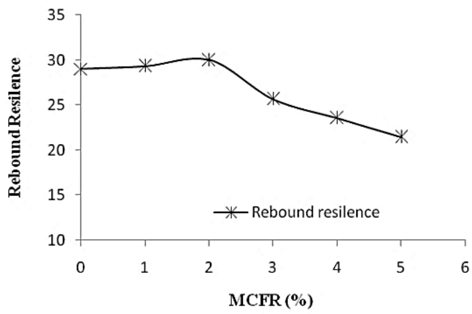

Figure 4: Rebound resilience variation with respect different % of MCFR.

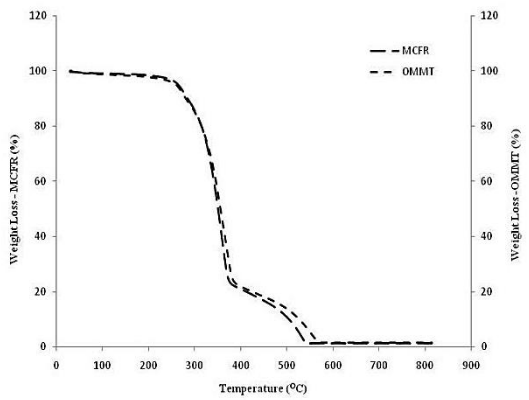

Figure 5: Themogram of MCFR (1 %) and OMMT (1 %) FPUF.

4. CONCLUSION

The present investigation shows that cell structure of the developed FPUF of different percentage of MCFR and OMMT is uniform without disintegration with respect to the control. Density of the FPUF was found to be increased with the increase in FR content. It was observed that FPUF developed with 1 % MCFR and 1 % OMMT content resulted with UL-94 rating of V-0 (Best). The increase in the content of FR does not show remarkable effect on the UL – 94 rating. Tensile strength was found to be maximum at 4 % of MCFR with the value of 0.145 Mpa. Thermal properties show that the incorporation of MCFR and OMMT has an FR effect when compared with the control. The present study confirms that the flexible polyurethane nanocomposite foam developed was effective and efficient with enhanced flame retardant characteristics.

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