The Application of Thermal Building Nano-Insulation Materials Based on the Diffusivity Characteristic of Polyurethane Nanocomposite

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Abstract—The paper aims to study diffusivity measurement of polyurethane (PU) nanocomposite with incorporation of montmorillonite nanoclay cloisite B30 (B30) prepared by solution intercalation method using chloroform as a solvent. The mixed compositions based on PU/B30 were analyzed according to the following weight percentage using 0.5%, 1%, 2% and 4% of montmorillonite nanoclay cloisite B30. The morphology of the samples was observed through Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectrometer (FTIR). The observation of SEM showed PU/B30 is not miscible meanwhile FTIR revealed that the surface segregation of the montmorillonite nanoclay cloisite B30 had not affected in PU. Next, water permeability test was conducted using nitrogen gas with different pressures. The pristine PU shows the lowest time taken for both pressures and contrary to the PU nanocomposite. This is supported by water absorption test in which the PU nanocomposite absorbs more water rather than the pristine PU.

Index Terms—Polyurethane, insulation, mechanical characteristics, nanocomposite.

I. INTRODUCTION

Thermal insulation in building reduces the rate of heat transmission across these building elements, but nowadays, higher cost is needed to provide higher energy saving because of the thicker insulation has been applied [1]. So, the alternative way that has been chosen is by replacing polymer nanocomposite as the main component for thermal insulation materials. Polymer nanocomposite has gained much attention for development in many interests recently [2]. Thus, polymer nanocomposite leads to enhance the properties of polymer itself. There are several publications regarding to the incorporation of nanocomposite in polymeric matrixes in term of enhancing the polymer properties and builds a new product [3, 4]. For instance, the improvement has been found in mechanical, thermal, permeability and diffusivity manners [5]. Previously, many industries are aiming on microcomposite technology. As comparing the microcomposite and nanocomposite, nanocomposite is lower in size and provides more surface area for interfacial interaction [6]. Polyurethane is a thermoplastic polymer with unique properties as simultaneously it can be a thermoset polymer after the addition of cross-linking agent [7]. Moreover, PU has a good compatibility and a preferable mechanical property made it is one of the most versatile polymers for many different of application [8]. Basically, PU received much attention in thermal building insulation because this type of polymer can improve appearance and lifespan for coatings and has as well as low maintenance cost [9]. The objective of this study is to synthesize a very thin thermal building (TIM) material using polyurethane-clay insulation nanocomposite via solution intercalation method, besides characterize PU nanocomposite using SEM and FTIR and investigate the material by means of diffusivity properties.

II. EXPERIMENTAL SECTION

A. Materials

PU and Cloisite B30 was the main material in this research. PU (flash point; 400 °C, density; 1.22 g/cm³, tensile strength; 25 MPa, elongation at break; 750 %) was obtained from Innovative Pultrusion Sdn Bhd meanwhile Cloisite B30 (ignition temperature; 190 °C, deflection temperature at 46 MPa; 96 °C decomposes at approximately 200 °C, specific gravity; 1.9 - 2.1 g/cm³) was obtained from Southern Clay Products Inc., USA. The chemical solution consumed was chloroform (molecular weight, Mw; 119.38 g/mol, CAS number; 67-66-3) which is used as solvent was obtained from Fischer Scientific (M) Sdn Bhd.

B. Synthesis of PU and PU Nanocomposite

1) Preparation of pristine PU

Pellet forms of PU were dried in a dry oven at 80 °C for at least 3 h. Two grams of PU was dissolved in chloroform solvent with 50 mL followed by the whole solution was magnetically stirred and heated at 80 °C for 5 h to form a well dissolved solution. Then, the solution was degassed and the solvent was removed at room temperature for 24 h and at last, an elastic and rubbery film was produced.

2) Preparation of PU Nanocomposite

Pellet forms of PU and cloisite B30 were dried in a dry oven at 80 °C for at least 3 h. The different series of B30 (0.5 %, 1 %, 2 % and 4 %) were stirred vigorously in chloroform solvent with 50 mL for an hour. After that, PU pellet forms with according weight percentage (99.5 %, 99 %, 98 % and 96 %) were added in the solution and stirred for 5 h. At room temperature, the PU nanocomposite solutions were formed by casting in petri dishes and removed the solvent at room temperature for 24 h.

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3) Methodology

The surface morphology and structure of the fabricated thin film and nanoclay were investigated by CARL ZEISS EVO Analytical Field Emission Scanning Electron Microscopy. The samples for SEM were coated with platinum using Pt coater and examined at an accelerating voltage of 15 kV. The water permeability was carried out based on the specification of ASTM D570 was conducted for water absorption test and the specimen was performed as round shape with diameter 80 mm. All series of the samples were dried in a dry oven at 80 °C for 24 h. Then, the samples were cooled in desiccators and instantaneously weighed every sample. The first weights of the samples were symbolized as W_0 . Afterwards, the samples were wholly immersed in deionized water for 24 h at room temperature. Subsequently, removed water on the surface of samples with clean dry cloth and instantly, all the samples were weighed to get final weight, W_1 . The formula (W_1 – $W_0)/W_0$ was used to calculate the percentage of weight increase of every sample to the nearest 0.01 %.

III. RESULT AND DISCUSSION

A. Morphology

SEM is employed to study how the B30 dispersed in the PU matrixes. Fig. 1(a) shows the fracture of nanofiller which is B30 particles in nano-scale sized. For the pristine PU in Fig. 1(b), there is some PU fracture that is not dissolves well in chloroform. For the Fig. 1(c), (d), (e) and (f), the micrographs of the samples show there are so many agglomerates form. This is due to the nanofiller is not well dispersed while in the stirring stage and assembled at a certain area. Moreover, in the micrographs can be seen that the dispersion might be intercalated or exfoliated due to the agglomerates formed in the samples. The nanofiller blocked the polymeric molecules from entering the silicate layered by enlarging the molecular spacing. This is supported by the poor interaction between matrixes and fillers will result bad manners despite of by adding fillers will enhance the properties of the polymer [10].

The other morphology analysis that has been conducted is FTIR shown in Fig. 2. In the figure, there are no obvious different between all the samples which mean that all the peaks found in the figure have identical with each sample. Thus, there are no chemical reactions involved between the polymer matrixes and the nanofiller as well as B30 has not affected the polyurethane segmented structure because FTIR did not indicate any change in PU. All the samples inhibit the same infrared spectra peaks at 2917 cm⁻¹ indicates that the –CH stretching of –CH₃ [11]–[13].





Fig. 1. SEM micrographs of fracture surface of (a) B30, (b) pristine PU, (c) 99.5% PU + 0.5% B30, (d) 99% PU + 1% B30, (e) 98% PU + 2% B30 and (f) 96% PU + 4% B30.



Fig. 2. The FTIR spectra of the different prepared samples.

At the peaks at 1732 cm^{-1} , -C=O is being free and hydrogen bonding is formed [14]. So, this can be concluded that there is no chemical reaction involves in the PU and PU nanocomposite and this also shows the chemical structures for PU and PU nanocomposite has no any changes.

B. Diffusivity Analysis

The presence of B30 in PU reduces the water transmission to pass through the segmented structures in PU, besides lowering the permeability. The result of water permeability of all the series are shown in the Fig. 3. The observation for composition of 98% PU + 2% B30 illustrates a bit different for pressure at 3 bars of value 512 s that is higher that 96% PU + 4% B30. This is might be happened due to the agglomeration of B30 formed as in Fig. 1(e). The time consumed by every sample shows constantly increasing for pressure at 4 bars. That means the corporation of B30 in PU improved diffusivity behaviour even though there are a slight different for pressure at 3 bars. This can be explained by a factor of the impermeable nanofiller structure specifically increased the tortuosity of transport path [15]. Fig. 4 described the tortuosity of transport path in the PU nanocomposite. The figure illustrates tortuous path made by fillers retard the flow of water molecules to pass through the polymeric components.







Fig. 4. The illustration of the water tortuosity of transport path through the polymer nanocomposite structure.

Water absorption was carried out according to ASTM D570 and the measurement was calculated by using Eq. (1).

Water absorption (%) =
$$(W_1 - W_0)/W_0 \times 100$$
 % (1)

where W_1 represents the final weight after water absorption and W_0 the dried weight of the sample after drying. The result is demonstrated in Fig. 3. The polar of the percentage is increased persistently based on the result showed in Fig. 3 except for the series of 98% PU + 2% B30. The water absorption ratio increased with the content of the nanoclay. This reason probably contributed by the agglomerate and not even contribution while preparing the solution. The water absorption of the samples body is attributed by the water rich of the nanoclay. Other than that, the higher volume of nanoclay will increased the difficulty for water molecules to flow through the network of PU nanocomposite. [16], [17].

IV. CONCLUSION

Incorporation of PU/B30 has proved that the improvement in diffusivity manner. PU nanocomposite has been synthesized with the nanometer scale silicate layers of organoclay completely in PU. Based on the SEM figure, there is agglomerates form in the samples. The PU segmented arrangement was not interfered by the presence of B30 regarding to there are no chemical structure changes as shown in FTIR result. PU nanocomposite imparts better water permeate properties as an efficient approach to promote the presence of B30. Additionally, PU nanocomposite based B30 has a special manner that possible to absorbs more water and this character may give an advantage in producing thermal building insulation material.

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