Influence of Expandable Graphite and Aluminium Hydroxide on Mechanical Properties of Polyurethane Foam

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Abstract. In this research, the influence of expendable graphite (EG) and aluminium hydroxide (ATH) on mechanical properties of polyurethane composite were investigated. Polyurethane foam was prepared by using oil palm based polyurethane with ratio 1:1.1 and mechanical properties was evaluated by compression test. Results shows that the addition of expendable graphite and aluminium hydroxide into polyurethane had improved the compression strength compared to polyurethane composite without additif. SEM micrograph shows the present of expendable graphite in the polyurethane cell wall which help to improve the mechanical properties. Especially, the compression strength at
10% EG/2% ATH loading sharply improved by 66% over polyurethane foam.

1. Introduction

Polyurethane (PUs) are polymers which have traditionally been produced by petroleum [1]. PU foam covers a wide range of applications including insulators, automotive interior, bedding, constructions, packaging, furniture, etc. Most of the rigid PU foam that currently available on the market are made from petroleum based polyester or polyether polyl. However, due to concern on environmental problems, researchers were driving the search of biodegradable and renewable materials as alternative to petroleum based materials. PU can be produced by reacting isocyanate (NCO) with polyl (OH). Palm based polyl and soy-based polyl known as natural oil based polyl are widely used to replace petroleum based polyl recently [2].

The other concern about that still not resolved is the polyurethane foams flammability-despite the very good thermal insulation properties. Foamed materials have a highly developed pore surface thus facilitate the access of oxygen to the materials which lead to easier combustion [3]. Typically, the main flame retardants of PU foam used are compounds containing halogen as well as antimony trioxide [4]. However due to problems related to large amount of toxic and corrosive gasses and smoke released during PU decomposition, researchers have found the halogen-free flame retardants. These include, among others, phosphines and their oxides, phosphonates, phosphates and phosphites, characterized by low toxicity, lack of release of toxic gases and production of small amounts of fumes during combustion. Furthermore, through the use of synergistic effect, flame retardant which contain, in addition to the phosphorus atom, additionally nitrogen, expandable graphite, inorganic compounds or halogen were used [5-11].

Expandable graphite (EG) is one of intumescent additive known to impart fire retardant to various materials and in particular to PU foam [12]. Weiguo et. al, has studied the synergetic flame retardant effect of EG in water-blow PU foam. They had found that EG together with ammonium polyphosphate has effectively improved the flame retardancy of semi rigid polyurethane foam. Furthermore, EG shows negative effect on the mechanical property which is decrease in compression modulus [13]. Several investigations have been devoted in recent years to incorporate fillers and additive in polymer matrix with purpose increase its mechanical properties. In this research, attempt has been made to use aluminium hydroxide (ATH) to increase the compression strength of EG/ polyurethane foam composite.

2. Methodology
2.1 Materials
Materials. Polyether polyol with amine catalyst (Maskimifoam 9935B/35) is palm oil based polyol while isocyanate (Maskimate 80) contains the mixture of Polymeric MDI with a concentration of 55% and Methylene Diphenyl Diisocyanate with 45% concentration. Both materials were supplied by Maskimi Polyol Sdn. Bhd. Additives used for polymerization of PUF are aluminum hydroxide (ATH) and expandable graphite (EG). Both of the additives were manufactured by Sigma-Aldrich.

2.2 Preparation of composites
PU foam composites were prepared according to the formulation in Table.1. The palm oil based polyol was stirred at 2000 rpm with a high speed mechanical stirrer and allowed to degass for 2 minutes. Then, EG and ATH were added into the polyol. The amount of EG and ATH were varied as shown in the Table.1. The mixture was stirred continuously until a homogenous. Later, the mixture was reacted with isocyanate and continuously stirred for 20 second. The mixture then was casted into a mold, covered and allowed to cure. The cured foam was removed from the mold after 24 hours. Then, the samples were placed in the oven for 2 hours at 80°C for post cure.

Table.1: Formulation for polyurethane foam composite based on ratio 1:1.1.

| Expandable graphite (EG) (wt%) | Aluminum hydroxide (ATH) (wt%) | Polyol (g) | Isocyanate (g) |
|-------------------------------|--------------------------------|------------|----------------|
|                               | 1st series | 2nd series | 3rd series |
| 5                             | 0          | 2          | 4          | 23.66 | 26.03 |
| 10                            | 0          | 2          | 4          | 23.66 | 26.03 |
| 15                            | 0          | 2          | 4          | 23.66 | 26.03 |

2.3 Mechanical test
Compression test for rigid cellular plastic was conducted under ASTM D1621-10 by using Instron 4206 machine. The cure PUF composites were cut by using a band saw machine with dimensions of 50 mm x 50 mm x 50 mm (length x width x thickness). Compression test was performed at room temperature with a constant crosshead speed at 10mm/min and the load was applied until the foam was compressed to approximately 80% of its original thickness. The samples were compressed in the direction parallel to foam rise. The strength and modulus of five specimens for a sample were measured and averaged.

2.4 Morphology
Scanning electron microscope (SEM) was conducted using JEOL JSM 6460 model. This analysis was done to determine the effect of additives and filler loading on foam cell size and distribution. It also reveals information about the sample surface morphology and mechanical properties. The samples were cut into 5 mm x 5 mm x 5 mm (length x width x thickness) and were coated with a very thin layer of platinum by using Auto Fined Coater to attain observation on the samples. Observation was made at 100 and 500 x magnifications.

3 Results and Discussion

3.1 Mechanical Properties
Figure 1 and Figure 2 represent the compression strength and compression modulus of PUF composites with varying amount of EG and ATH in polyurethane foam. Generally, compression strength shows significant increment as the EG and ATH loading in PU foam composite increase compared to pure PU foam composite. Compression strength increase by 41% for (5%EG/2%ATH), 66% for (10%EG/2%ATH) and 60% for (15%EG/2%ATH). Generally, the achievement of good mechanical properties in filled PUF system was determined by the distribution and dispersion of filler in the polymer matrix [14]. It can be seen from the SEM micrograph that EG distributed well and located mostly on the foam cell struts as shown in Figure 3 (C) which can contribute to increases the strength and modulus of PUF composites.

Compression modulus shows increment trend as EG and ATH loading increased (Figure 3). Incorporation of EG and ATH will affect the formation of cell and cell wall in PU foam composite. PU foam composite with high loading percentage of EG and ATH will have ticker cell wall, smaller and more uniform cell size compared pure and lower percentage of EG and ATH. It was believed that ticker cell walls in PU foam composite
contributed to the foam stiffness and higher stress was required to impose cell bending, buckling and collapsed.

**Figure 1**: Compression strength of PU foam composites

**Figure 2**: Compression modulus of PU foam composites

### 3.2 Morphological properties
Figure 3 represents the morphology of PU foam composite. It can be seen that the addition of EG and ATH affects the cell size and cell distribution in overall PU foam composite. The cell size becomes smaller and more uniform for samples with 10% EG/4% ATH (Figure 3(B)) compared to pure PU foam composite (Figure 3(A)). The wall thickness, highlighted in red circle, increased for PU foam composite sample with 15% EG/4% ATH (Figure 3(C)). It also can be spotted in Figure 3(D) that the EG particles at the PU foam cell wall thus improve the overall mechanical properties of PU foam composite.

**Figure 3.** SEM micrograph of (A) Pure PU foam, (B) 10% EG/2% ATH PU foam, (C) and (D) 15% EG/4% ATH PU foam.

**4. Conclusion**

The incorporation of EG and ATH into palm oil based polyurethane foam has been carried out and Compression test shows that 10% EG/2% ATH shows the highest compression strength and 15% EG/2% ATH shows the
highest compression. This proved EG and addition of ATH will improve the mechanical properties PU foam composite.

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