Effect of Aluminium Filler Content on the Mechanical Properties of Polyurethane Foam

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Abstract. Start In this work, the effects of Aluminium (Al) filler content in Polyurethane (PU) foam with different weight percentages (0.5 wt.% to 3.0 wt.%) were evaluated on morphology, density and compressive strength. The pure PU and PU/Al foam composites were produced from palm oil-based polyol (POP) and methylene diphenyl diisocyanate (MDI) with a ratio of 1:1. Scanning Electron Microscope (SEM) morphology showed that the cell structure of PU/Al foam composites is less homogeneous as compared to the pure PU. The PU/Al foam composites displayed a higher number of cells with a smaller cell size as the amount of Al content was increased. The addition of 1.5 wt.% Al on the PU foam showed the highest density and compressive strength in 0.073 g/cm³ and 0.56 MPa, respectively. Meanwhile, the further addition of Al on PU foam has decreased the density and compressive strength value. The experimental compressive strength results have compared to the theoretical results that tested by using ANSYS MULTIPHYSICS (15.0) software.

1. Introduction
The Polyurethane (PU) foam has a special group of polymeric materials that are dissimilar from other plastic types. PU foam has a remarkably broad range of applications including insulators, automotive, refrigerators, mattress, construction, packaging, and several other industries because of its attractive characteristics in terms of lightweight, insulation materials, easy processing, and commercial potential availability [1, 2]. However, PU also presents some disadvantages, which prevents PU foam to be used in the structural industry due to its low mechanical strength [3]. To overcome this disadvantage, several types of fillers have been used to improve PU foam properties including inorganic materials such as dolomite, calcium carbonate, titanium dioxide, Aluminium (Al) silica, and talc, while some of the organic materials such as fillers are natural fibers and carbon black. Mechanical properties of PU foam also, basically, depends on their density and cell structure. PU foam with very fine cells and uniform cell distributions exhibits better mechanical properties [4].

Several work have been devoted in recent years to incorporate a metallic powders in polymer matrix with purpose to change its properties such thermal stability, conductivity or mechanical properties. Al fillers have high strength, low weight, easy machining, superior malleability, good corrosion resistance, and good thermal conductivity [5, 6]. The aim of this work is to investigate the effects of different Al contents on the morphology, density and compressive strength on the PU foam. The
optimum compressive strength for PU/Al foam composites was studied by using ANSYS MULTIPHYSICS (15.0) software.

2. Experimental

2.1. Materials and Preparation of PU/Al Foam Composites

The commercial Aluminium (Al) powders were provided by the Acros Organics BVBA, Belgium. The palm oil-based polyol (POP) PolyGreen R3110 were supplied by the PolyGreen Chemicals Sdn. Bhd., Malaysia, and the isocyanate was the methylene diphenyl diisocyanate (MDI) Maskiminate 80, obtained from the Maskimi Polyol Sdn. Bhd. The PU foam was produced with a ratio of 1:1 to POP and MDI in presence of distilled water as a blowing agent. The POP was stirred at 2000 rpm until it turned milky yellow in color (for about 4 minutes). Then, the MDI was added and the mixtures were stirred for 15 minutes. Various Al filler contents were added into the mixtures as given in Table 1. The distilled water was added and continuously stirred for 4 minutes before placed in a mould. The PU/Al foam composites samples were cured at room temperature for 24 h and continued to be post cured for 2 h at 80°C.

| Sample       | Palm oil-based polyol (POP) | Methylene diphenyl diisocyanate (MDI) | Aluminium (Al) | Distilled water |
|--------------|-----------------------------|---------------------------------------|----------------|-----------------|
| Pure PU      | 1                           | 1.1                                   | -              | 0.1             |
| 0.5 % PU/Al  | 1                           | 1.1                                   | 0.5            | 0.1             |
| 1.0 % PU/Al  | 1                           | 1.1                                   | 1.0            | 0.1             |
| 1.5 % PU/Al  | 1                           | 1.1                                   | 1.5            | 0.1             |
| 2.0 % PU/Al  | 1                           | 1.1                                   | 2.0            | 0.1             |
| 2.5 % PU/Al  | 1                           | 1.1                                   | 2.5            | 0.1             |
| 3.0 % PU/Al  | 1                           | 1.1                                   | 3.0            | 0.1             |

2.2. Testing and Characterization

Scanning Electron Microscope (SEM) was used to observe the cell morphology of the PU/Al foam composites. From the SEM micrographs, the average cell size was obtained by using the Smile View software. The density was calculated from the ratio between the weight and volume of the foam samples. The compression tests were done by using the INSTRON Universal Testing Machine (UTM) according to ASTM D1621 at the crosshead speed of 10 mm/min with samples foam of 50 mm × 50 mm × 50 mm (width × length × thickness). The compression test results were compared to the theoretical results that were analyzed by using the ANSYS MULTIPHYSICS (15.0) software.

3. Results and Discussion

3.1. Morphology

The morphology of pure PU and PU/Al foam composites with different Al contents were observed using SEM, as can be seen in Figure 1(a-g). From these figures, the PU/Al foam composites morphology showed less homogeneity with the addition of Al fillers compared to the pure PU. The addition of Al fillers into the PU foam was found to have higher number of cells with smaller cell size as the amount of Al was increased. The cell size, density and compressive strength results are shown in Table 2.
Table 2: Density and compressive strength of pure PU and PU/Al foam composites.

| Sample        | Cell Size (µm) | Density (g/m³) | Compressive strength (MPa) |
|---------------|----------------|----------------|---------------------------|
| Pure PU       | 1360           | 0.0680         | 0.077                     |
| 0.5 % PU/Al   | 842            | 0.0690         | 0.085                     |
| 1.0 % PU/Al   | 751            | 0.0710         | 0.087                     |
| 1.5 % PU/Al   | 711            | 0.0730         | 0.094                     |
| 2.0 % PU/Al   | 1142           | 0.0720         | 0.088                     |
| 2.5 % PU/Al   | 1427           | 0.0705         | 0.083                     |
| 3.0 % PU/Al   | 1681           | 0.0690         | 0.082                     |

Figure 1: SEM morphology of: (a) pure PU, (b) 0.5 % PU/Al, (c) 1.0 % PU/Al, (d) 1.5 % PU/Al, (e) 2.0 % PU/Al, (f) 2.5 % PU/Al, and (g) 3.0 % PU/Al foam composites.

3.2. Density

Figure 2 displayed the effects of Al content of pure PU and PU/Al foam composites on density. The pure PU showed the lowest density as compared to the PU/Al foam composites. The addition of Al content to an optimum content of 1.5 wt.% was increased to the highest density of PU/Al foam composites with more number of cells and smaller cell size. Further addition of Al content after 1.5 wt.% showed that the decreasing density might be due to the agglomeration of Al filler. The Al cannot act as an effective nucleating agent to stabilize the foaming process; one of the consequences is that it can cause an inhomogeneous, larger cell size and alter the cell structure, which results in the decreasing PU/Al foam composites density [4].
3.3. Compressive Strength

Figure 3 showed the changes of compressive strength from pure PU to 3 wt.% Al content on PU/Al foam composites that were divided into two stages, which takes on the trend of rising first, then, the dropping trend with increasing Al filler content. The addition of Al content until 1.5 wt.% was increased to the highest compressive strength due to the good adhesion between the Al filler and PU matrix. The stress transfers from PU matrix to the Al when the PU/Al foam composites were compressed had also contributed to the increasing compressive strength. However, the compressive strength had decreased, while the Al filler was added continuously after the optimum content of 1.5 wt.% This decreasing trend can be explained by the agglomeration that tends to occur when the Al content is in excess and hence, cannot be dispersed uniformly [7]. The compressive strength results tallied with the density results as shown in Figure 2.

3.4. Simulation

The experimental results from the highest compression strength with 0.0924 MPa at 1.5 wt.% PU/Al foam composites were compared to the theoretical results that were tested by using the ANSYS MULTIPHYSICS (15.0) software. The modeling and photographs taken during the test work are shown in Figure 4(a-c). The modeling started with the blue color and the change of color indicated the different stress that passes through the 1.5 wt.% PU/Al foam composites. In the end, the red color
revealed that the 1.5 wt% PU/Al foam composites have the highest stress with a theoretical result of 0.092 MPa. The correlation between the theoretical and experimental results displayed in small changes (2%) may be due to the PU foam process or temperature while conducting the compression test.

Figure 4: Modeling of compressive strength of 1.5 wt.% PU/Al foam composites: (a) before test, (b) during test, and (c) after test.
4. Results and Discussion

In this work, SEM micrographs have discovered that the addition of Al filler content in the PU foam had contributed to an inhomogeneous cell structure when compared to the pure PU. It was also found that the addition of Al content presented a higher number of cells with a smaller cell size. The incorporation of Al filler to 1.5 wt.% into PU foam had increased the density and compressive strength results. The correlation between the theoretical and experimental results displayed in small differences.

5. References

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