

Dynamic Mechanical Analysis of Synthetic epoxy (E) and Bio-epoxy Polymer Foam Integrated with Wood Filler Under 8000 hours Exposure to UV Irradiation

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DOI: <https://doi.org/10.30880/emait.2020.01.01.003>

Received 17 September 2020; Accepted 01 October 2020; Available online 01 November 2020

Abstract: The most common sustainable polymer for polyurethane (PU) materials is the production of polyurethane (PU) materials using renewable resources, which will reduce the dependency on petroleum-based products for consumption. This research presents findings from an experimental research on dynamic mechanical and viscoelastic properties such as storage module (E'), loss module (E'') and damping coefficient ($\tan \delta$) of synthetic epoxy (E) and bio-epoxy (B) polymer foam with different loading ratios of 0%, 5%, 10%, 15% and 20% flakes and powder filler. The samples were then exposed to 8000 hours of UV irradiation. The samples were subjected to dynamic mechanical analysis (DMA) over a temperature range of 25-180 °C for (E) and (B) polymer foam at a frequency of 1 Hz. The results showed that the 20% synthetic epoxy with flakes filler material, namely as E20L sample with the highest filler ratio, gives the maximum storage module and loss module values (0.3125 MPa and 0.0625 MPa respectively), among other filler ratios due to bonding between foam and filler resulting in increased viscosity of the synthetic-epoxy PU foam. The bio-epoxy PU foam with a 5% powder filler material (B5P), has the highest storage value (3,956 MPa) and loss module (17,213 MPa), showing that bio-epoxy PU foams can dissipate energy faster than synthetic-epoxy polymer foams. Thermogravimetric analysis (TGA) showed that the synthetic epoxy (E) polymer foam had a higher Tg value and the highest value was reported by E5L (1.2) compared to bio-epoxy foams with far less repeatable results due to the less homogeneous polyol structure.

Keywords: Synthetic-epoxy, Bio-epoxy, Dynamic Mechanical Analysis, Glass transition, Wood filler

1. Introduction

The concerns regarding petroleum-based asset use and environmental problems caused by petroleum-based materials have led to widespread efforts to produce renewable-asset-dependent materials such as vegetable oils, cellulose, lignin, starch, etc [1]. Due to the degradability and low toxicity of the resulting goods, the use of natural raw materials will ultimately contribute to sustainable development. Due to their lightness, reduced thermal conductivity, high-energy absorption, and excellent strength / weight ratio, polymeric foams are commonly used in various fields. There is a wide range of application areas for polymer foams, such as transportation, bedding, carpeting, textiles, toys, sports equipment, insulation and building equipment, biomedical and automotive sectors [2]. The reaction between an isocyanate prepolymer and a polyol in the presence of a blowing agent and an amine (catalyst) shapes PU foams. Methylene diphenyl diisocyanate or toluene diisocyanate are examples of diisocyanate types [3].

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For the polymer industry, the most studied renewable resources are currently focused on plant oil, starch, wood and cellulose [4]. Waste cooking oil (WCO) is produced worldwide on a large scale; it has therefore established serious problems with its waste management and causes some serious environmental problems, including bad odor [5]. The petroleum-based products can be replaced by recycled waste oil can also be used to enhance physical and mechanical properties and minimise environmental emissions. Wood fibres are plant structural materials and are the most plentiful biomass on earth. Wood fibres are known for paper production, and the fibres are obtained from various national resources as fillers materials and have advantages as they are available with easy maintenance in light, cheap, environment-friendly forms [6]. Wood waste is biodegradable, lightweight, cheaper, non-toxic and, with environmental and economic benefits, and has non-abrasive properties [7].

In this analysis, the polymer foams will be produced using petroleum-based synthetic-epoxy and bio-epoxy. To examine the mechanical and physical characteristics of the polymeric foams, the PU foams were introduced with wood filler into the foam composite.

2. Methodology

2.1 Sample preparation

The epoxy and isocyanate were initially mixed in a cup for 15 minutes with a Philips Multiple Speeds Handmixer until homogenous, different composition ratios were used as shown in Table 1. The synthetic epoxy foam, (E) with added wood filler (powder, P & flakes, L) were manufactured [8-14] at 5 %, 10%, 15% and 20% loading percentages. The fabricated samples for petroleum-based composite and bio-epoxy-based composite were labeled as shown in Table 1. For an example of the nomenclature, label E5P was given for the petroleum-based composite (E), with 5% wood filler (5) in powder form (P).

Table 1 - Different types of polyurethane (PU) composite samples

Type	Name	Filler Content(wt%)	Type of Filler
Petroleum-based Epoxy foam	E0	0	
	E5P	5	
	E10P	10	Powder
	E15P	15	
	E20P	20	
	E5L	5	
	E10L	10	Flakes
	E15L	15	
	E20L	20	
Hydroxylated-bio Epoxy foam	B0	0	
	B5P	5	
	B10P	10	Powder
	B15P	15	
	B20P	20	
	B5L	5	
	B10L	10	Flakes
	B15L	15	
B20L	20		

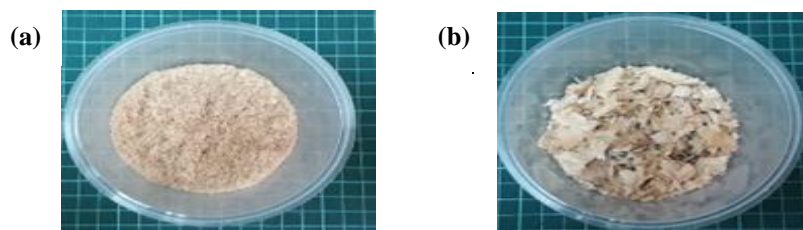


Fig. 1 - (a) powder filler; (b) flakes filler

2.2 Irradiation Source

In the UV-Weatherometer chamber at 50 °C, with an exposure time of 8000 hours, the EL, EP, BL and BP polymer foam composites were mounted on a rack with a rack holder. According to ASTM D 4587-Standard Procedure, the UV accelerated weathering for fluorescent UV-condensation exposures. An array of UV fluorescent lamps emitting light in the 280 to 320 nm region with a tail ranging to 400 nm was used for UV irradiation.

2.3 Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis (DMA) is a sensitive technique characterising the mechanical responses of materials by measuring changes in the properties of a material with respect to temperature and frequencies. Dynamic mechanical study, using TA instrument Q800 has analysed the viscoelastic properties of the synthetic epoxy (E) and bio-epoxy (B) polymer foams. The foam specimens were cut into a rectangular shape with a dimension of 40 mm x 10 mm x 5 mm. DMA of the synthetic foams with a ramp rate of 4°C / min was carried out up to 180°C. A single cantilever bending mode with a frequency of 1 Hz was used to test the samples. The effects on storage modulus, loss modulus and tan delta of E and B foams of the filler content and temperature were examined. Parameter settings are as shown in Table 2.

Table 2 - Setting Parameters for the DMA machine of a single cantilever

Parameters	Value
Heating Rate	4°/min
Temperature Range	25°C - 180°C
Frequency	1 Hz
Dimension Shape	Rectangular (40mm X 10mm X 5mm)

3. Results and Discussions

3.1 Glass Transition Temperatures (T_g) of PU Foams

The variation of the tan delta defined as the ratio of the modulus of loss to the modulus of storage, as a temperature function. The glass transition values (T_g) versus the filler ratio of synthetic epoxy (E) and bio-epoxy (B) polymer foams with wood powder filler (P) after exposure to UV irradiation for 8000 hours are presented in Fig. 2. It is evident from Fig. 2(a) that E5P has the highest T_g value, which is 1.2, and is greater than synthetic epoxy foam without filler, E0, which is 0.68. The synthetic epoxies of E10P and E15P have comparatively lower T_g values. It is noticeable in Fig. 2(b) that the T_g of the bio-epoxy foams decreased as the powder content increases, except for bio-epoxy foams containing 20% wt of (P) wood filler. The reinforcing impact of the powder particles led to improved stiffness of bio-epoxy foams. Among other filler ratios, the B20P bio-epoxy foam is found to have a maximum T_g value of 0.351, which is lower than T_g of B0 by 50% (0.68).

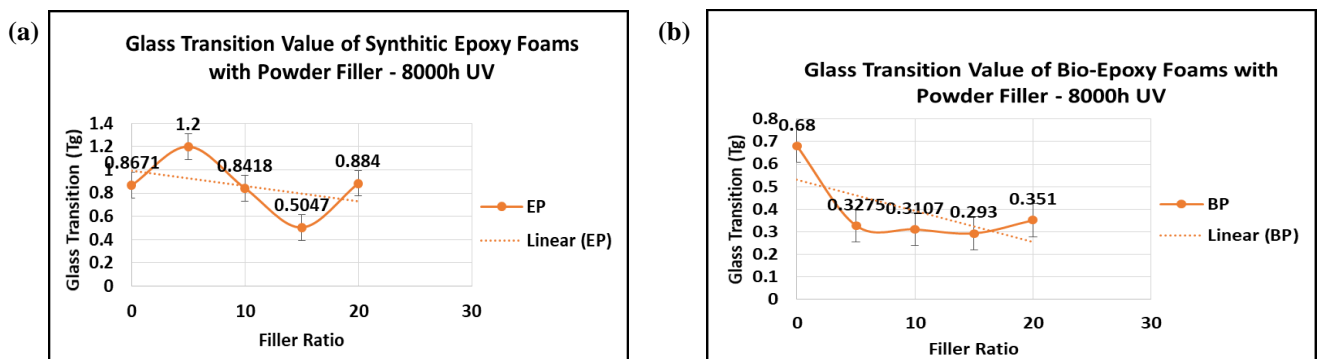


Fig. 2 - Glass Transition values of (a) synthetic epoxy (E); (b) bio-epoxy (B) polymer foams with powder filler

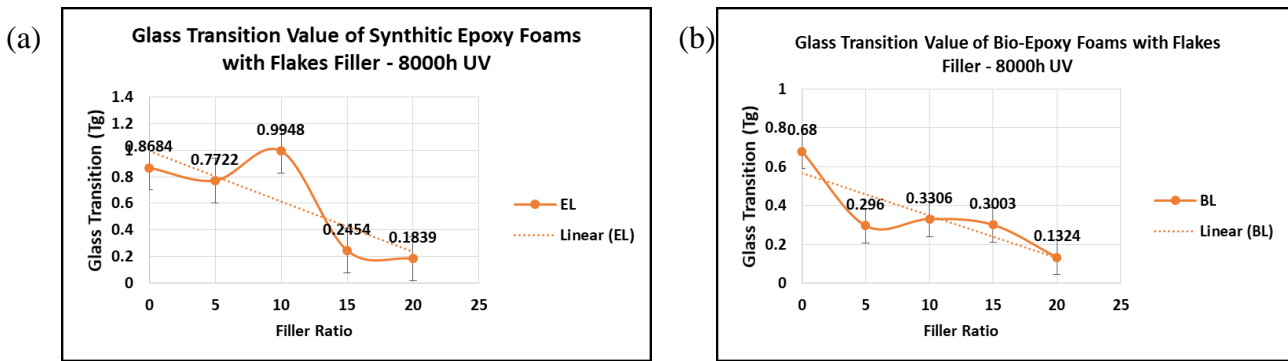


Fig. 3 - Glass Transition values of (a) synthetic epoxy (E); (b) bio-epoxy (B) polymer foams with flakes filler

Fig. 3 shows the glass transition temperatures of synthetic epoxy (E) and bio-epoxy (B) polymer foams filling with different ratio of wood flakes filler. Fig. 3(a) shows that E10L synthetic epoxy (E) achieved the highest T_g value compared to other filler content. Among other filler ratios, B10L has the highest glass transition value in the case of bio-epoxy (B), but is 50% lower than bio-epoxy without filler (B0). Compared to bio-based samples, samples manufactured from synthetic epoxy have a higher T_g value than E15L, which is attributed to the less homogeneous bio-based structure.

3.2 DMA for Storage and Loss Modulus (E' and E'')

In the manufacture of polyurethane composite foams, the use of fillers contributes to different viscoelastic responses under applied stress. Viscoelastic reactions may be used to determine the material storage and loss modulus [15]. The storage modulus is the ability of the material to store energy under the force applied, and it is closely related to the elastic properties of the foams in order to withstand the long-term use of high load conditions. The results of the storage (E') and loss modulus (E'') of synthetic epoxy (E) and bio-epoxy (B) polymer foams for different flake (L) fillers content after exposure to UV irradiation for 8000 h are shown in Figs 4 and 5. With an improvement in the filler content of both synthetic epoxy (E) and bio-epoxy (B) polymer foam, the storage modulus (E') increased to the additional stiffness of the cell wall by the fillers, however there is a sudden decrease of E' in E10L and a substantial improvement achieving the maximum value of E' on B5L (17.213 MPa). Among other filler ratios, synthetic epoxy E20L had the maximum E' (0.3125 MPa) due to the bonding of synthetic epoxy foams with filler, resulting in increased synthetic epoxy foam viscosity. Fig. 4(b) shows that bio-epoxy (B) polymer foam with flake filler has higher storage modulus values compared to synthetic epoxy (E) and the maximum E' value was obtained in B5L (17,213 MPa). At a temperature range of 50 °C to 80 °C, the modulus curve for bio-epoxy polymer drops, while synthetic-epoxy polymer takes longer to drop.

As the content of the filler increased, E'' values of synthetic epoxy (E) increase as shown in Fig. 5(a), which indicates that the microstructural deformation between the fillers and polymer interfaces might increase at a high filler content. Synthetic-epoxy E20L sample has the maximum loss modulus value (0.0625 MPa). The curve in Fig. 5(b) shows that B5L (3,956 MPa) has the highest loss modulus value, among others. Bio-epoxy polymer foams can dissipate energy faster than synthetic epoxy polymer foams. The discharged energy is lost in the form of heat.

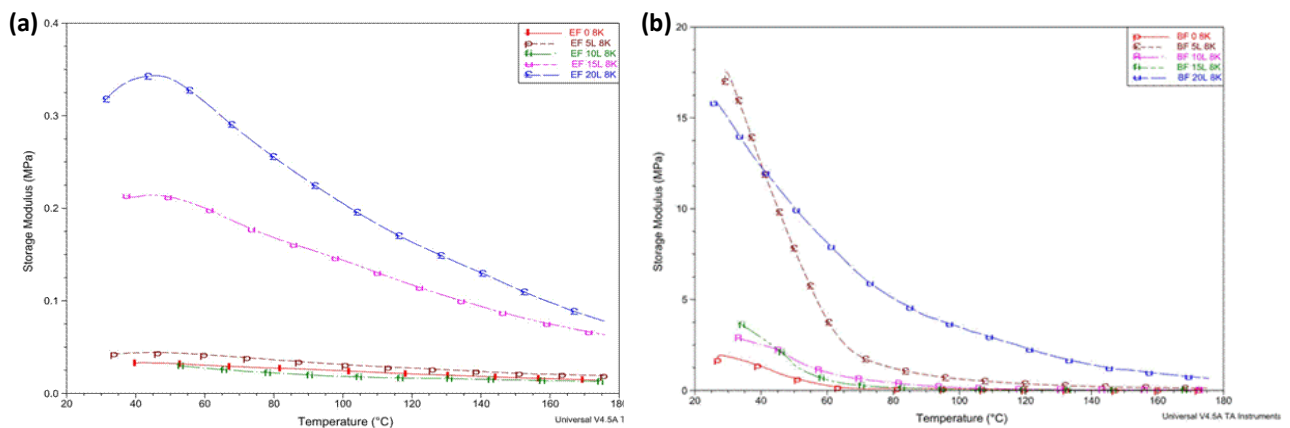


Fig. 4 - Storage Modulus values of (a) synthetic epoxy (E); (b) bio-epoxy (B) polymer foams with flakes filler

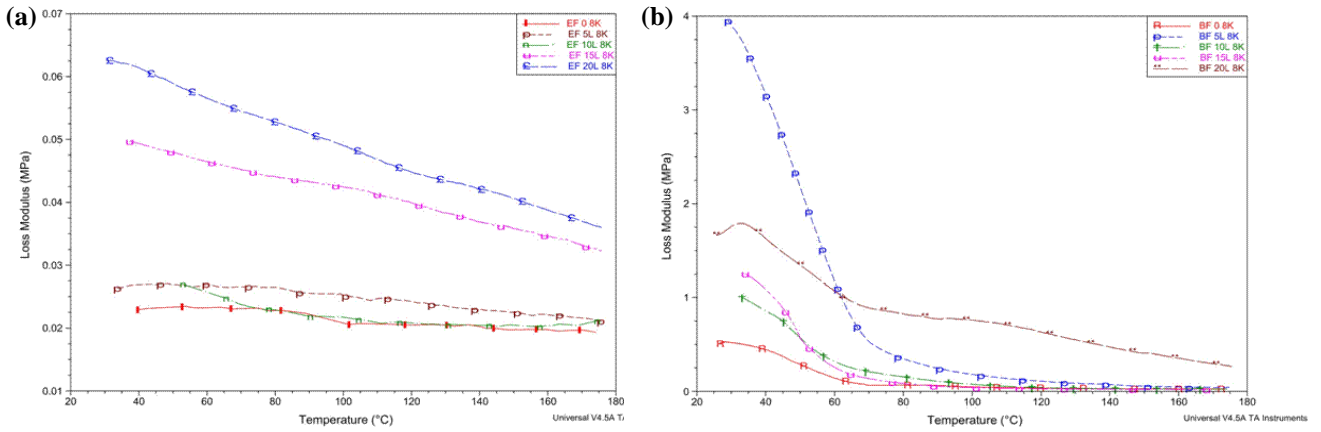


Fig. 5 - Loss Modulus values of (a)synthetic epoxy (E); (b) bio-epoxy polymer foams with flakes filler

Fig. 6 and 7 display the storage modulus and loss factor versus temperature plot of synthetic-epoxy polymer (E) and bio-epoxy (B) polymer foams containing different amounts of wood powder filler (P) after 8000h UV irradiation exposure. Synthetic-epoxy E15P was the highest (0.0866 MPa) among other samples, shown in Fig. 6(a), which can be seen to show that high viscosity polymer foams have a high ability to store energy and produce a high elasticity material. In the case of bio-epoxy foam, as shown in Fig. 6(b), the storage modulus is substantially higher than that of synthetic epoxy and the maximum value (11.8 MPa) of B10P was obtained. The temperature of bio-epoxy polymer foams decreased rapidly, shown in Figs 6(a) and 6(b), while synthetic foam took longer time to lower the temperature.

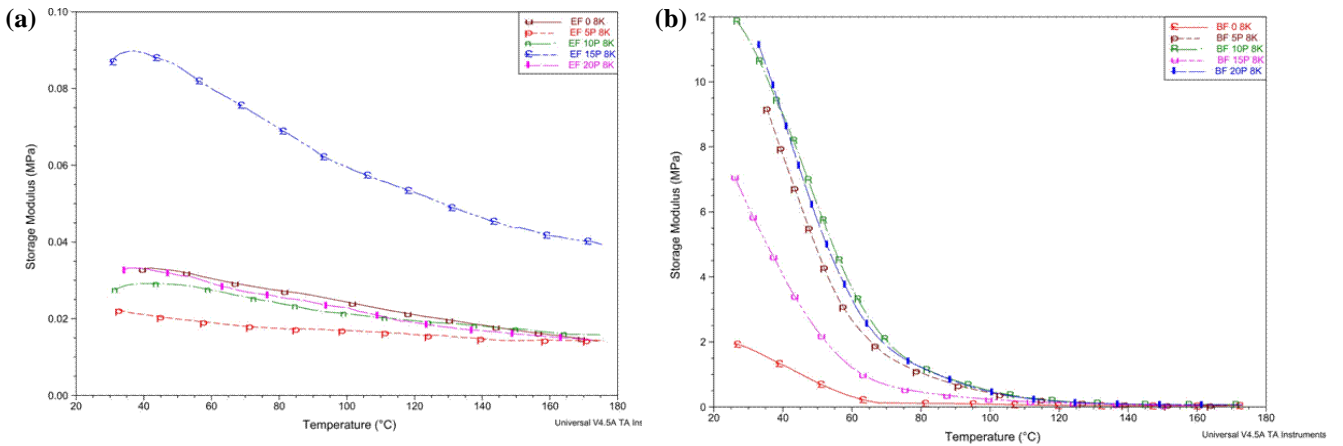


Fig. 6 - Storage Modulus of (a) synthetic epoxy (E); (b) bio-epoxy (B) polymer foams with powder filler

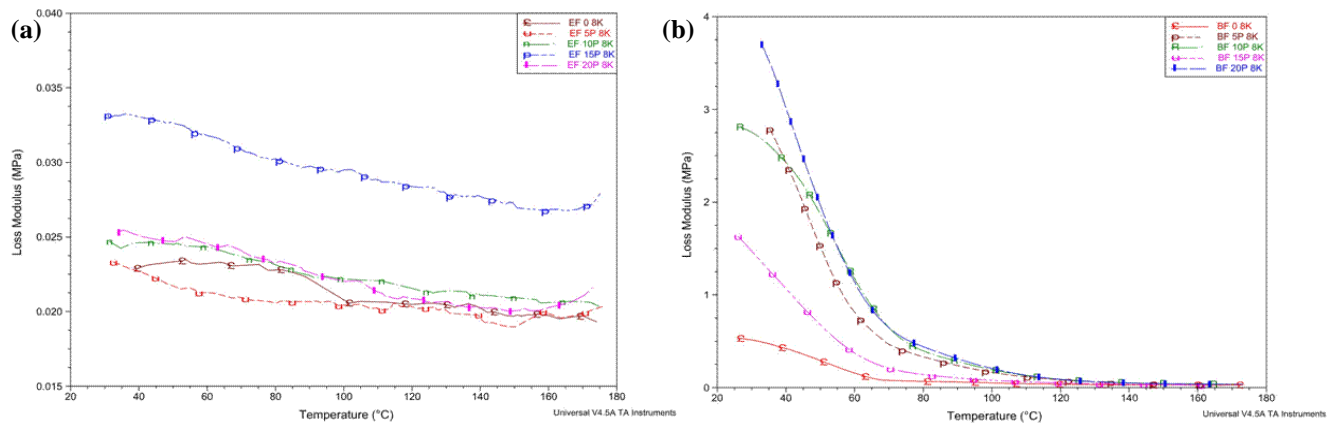


Fig. 7 - Loss Modulus values of (a) synthetic epoxy (E); (b) bio-epoxy (B) polymer foams with flakes filler

From Fig. 7(a), the E15P sample had the highest loss modulus value (0.0329MPa) among other filler content. Fig. 7(b) shows that, among others, B20P (3.75 MPa) had the highest loss modulus value. Due to restricted epoxy resin movement in the vicinity of cenosphere particles, the loss module of synthetic foams was lower than the bio-epoxy foams.

4. Conclusion

Polymer foams of synthetic epoxy (E) and bio-epoxy (B) containing different quantities of powder (P) and flake fillers (L) were prepared. All fabricated samples were exposed for 8000 h to UV irradiation. Dynamic mechanical properties were analyzed for EL, EP and BL, BP. The highest glass transition (T_g) value compared to bio-epoxy foams, which had far less repeatable results due to the less homogeneous polyol structure, was achieved from glass transition test E5L (1.2). The modulus of storage and loss modulus vs temperature plots have been examined. The highest values of E' and E'' (0.3125 MPa and 0.0625 MPa respectively) were achieved by Synthetic-epoxy (E) E20L. The highest storage value (3,956 MPa) and loss modulus (17,213 MPa) in the case of bio-based (B5P) suggests that bio-epoxy PU foams can dissipate energy more quickly than synthetic-epoxy polymer foams.

Acknowledgement

The author would to thank the Ministry of Education Malaysia and University Tun Hussein Onn Malaysia (UTHM), Johor, for supporting this research study under research grant Vot H378.

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