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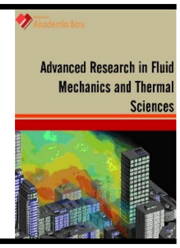

Preparation and Characterization of Natural Fiber Filled Asphalt Based Damping Material

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ABSTRACT

Asphalt based damping material filled with glass fiber is commonly used as free layer damping material (FDM) for body-in-white of automotive industry. However, the manufacturing of artificial material and end of disposal are the major problems to the environment. To overcome this problem, synthetic materials are being replaced by natural fibers as fillers. This research involves the production and characterization of FDM with different weight percentage (0, 5, 10, 15) of kenaf fiber loadings. The FDM composites were produced through mechanical mixing and hot pressing process. For damping performance, FDM with 10% kenaf fiber loading shows the maximum dynamic modulus and loss factor in Dynamic Mechanical Analysis and Oberst Beam Method test respectively. FDM with 10% fiber loading also shows the lowest weight loss due to thermal degradation as compared to other FDM composites. FDM with 10% kenaf fiber loading provides the best damping performance among all the FDM composites (0 ~ 15%) at room temperature which may attribute from the better viscoelastic nature of asphalt and kenaf fiber.

1. Introduction

In today's world, automotive manufacturers are required to decrease CO_2 emissions and increase the fuel economy while assuring driver comfort and safety. To achieve desired acoustic performance targets, automotive manufacturers use various free-layer damping sheet materials which they apply to Body-In-White (BIW) of the vehicle with the goal to achieve better noise, vibration and harshness (NVH) management (quiet car) and lower weight per vehicle [1-5]. Most of these damping pads/sheets, so called asphalt sheets, are applied onto the floor pan inside the vehicle. These pre-manufactured and vehicle specific die-cut sheets are typically highly metal-carbonate, sulphate or silicate filled asphalt systems with a high specific gravity. Depending on the size of vehicle, the amount of these sheets can reach application weights of 10-20 kg/vehicle [1].

Over the last couple of decades, the needs in environmental friendly material are drawing attention in automotive industries [6,7]. There have been many researchers studied on the

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performance of natural fibers in vibrational damping properties [8-10]. Issue for replacing the artificial materials with natural fibers is to produce lighter damping material with an aim of fuel efficient vehicle and to reduce the emission of carbon [11, 12]. Moreover, they are biodegradable and recyclable which may reduce the landfilling impact. A few researches so far conducted to understand the effect of kenaf fiber loadings on the damping behaviour of the asphalt based damping material. This study is aimed to prepare and characterise the kenaf fiber filled asphalt based damping material with different fiber loadings. The mechanical properties of FDM were determined by Oberst Beam Method testing (OBM) and Dynamic Mechanical Analysis (DMA) while the physical properties of FDM were determined by density measurement, cyclic heat resistance test, optical microscopy (OM) and thermogravimetric analysis (TGA).

2. Methodology

Asphalt (bitumen 60/70) and non-woven kenaf fibers mat were obtained from Cascadian Asphalt Industries SDN Bhd. and KIRD Enterprise respectively. The non-woven fibers were shredded manually into smaller pieces followed by pulverisation in a Pulverisette 14 from Germany. The compounding process of asphalt and kenaf was carried out by mechanical stirring process on a hot plate. The weight percentage of each ingredient was summarized in Table I.

Table 1
Weight percentage of ingredient

Sample	Weight ratio (wt%)		
	Asphalt wt%	**Calcium Carbonate wt%**	**Kenaf Fiber wt%**
FDM-KF-0	50.0	50.0	0
FDM-KF-5	47.5	47.5	5
FDM-KF-10	45.0	45.0	10
FDM-KF-15	42.5	42.5	15

Initially asphalt was slowly heated above its softening temperature of 100°C. Then, the mixture of calcium carbonate and kenaf fibers was mixed throughout the asphalt with mechanical stirring process carried out simultaneously. Calcium carbonate was used to provide the stiffness of the asphalt samples. The mixture was poured into the mold and left to cool down to room temperature of 25°C. Finally sample was placed in 3 mm thick mould cavity and compressed in hot press GT7014-A from Gotech. Sample was preheated to 30° C for 5 mins and then further hot compressed at an applied stress of 150kg/cm^2 for 5 minutes at 60°C. Later damping material sheet was cooled to 25°C and withdrawn from mold. Damping sheets were cut into appropriate dimension as per ASTM E1640-13 and ASTM E756-05 standards for Dynamic Mechanical Analysis and Oberst Beam Method Testing (OBM) (DMA) respectively.

MD-300S Electronic Densimeter was used to determine the density of the sample. Three samples were used for each fiber loading to determine average value of density.

Heat resistance test of FDM composites was conducted in a Memmert drying oven. For each thermal cycle, samples were heated to 40° C at a heating rate of 5° C/min, held for 5 minutes at 40°C and cooled down to room temperature. Samples were withdrawn from oven after 10, 20, 30, 40 and 50 heating cycles and placed under the optical microscope to observe the condition of the interface between damping material and the mild steel substrate.

Dynamic mechanical analysis (dual cantilever mode) was carried out by a DMA8000 (Perkin Elmer) at a range of temperature from -100ºC to 50ºC, with constant frequency of 1Hz. The average dimensions of DMA samples were approximately 35 x 10 x 3 mm.

Oberst Beam Method testing was carried out to determine the loss factor (η) of FDM composites. Three specimens with size of 140mm x 10mm x 3mm were used for OBM test and cantilever beam length was constant at 180mm for all specimens. Schematic arrangement of cantilever steel beam and the placement of test sample are shown in Figure 1. The samples were held as a cantilever beam and an accelerometer was attached at the free end of each samples. Then, vibration frequency in the range of 100-1000 Hz was triggered by a mini shaker. Figure 2 shows the experimental setup of OBM test system.

(a) Cantilever steel beam

(b) Cantilever steel beam with test sample

Fig. 1. Schematic arrangement of test sample for OBM test

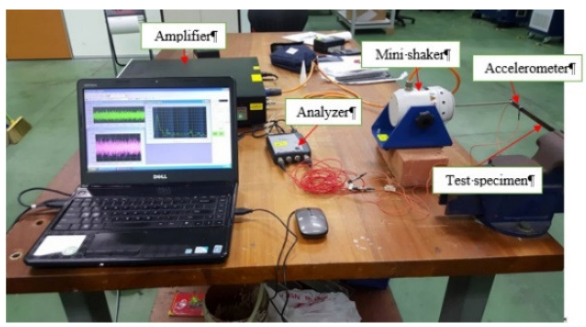

Fig. 2. Experimental Setup for OBM test method

Initially, the frequency response function (FRF) measured on the bare mild steel beam was analysed to determine natural frequencies within the frequency range of 100 to 1000 Hz. Then, measured FRF on the damped beam will be analysed to determine the natural frequencies and corresponding modal loss factors of the composite beam. Using the determined natural frequencies of the bare steel beam, and the natural frequencies and loss factors of the damped beam, modulus and damping level (loss factor) of the damping material was identified at frequencies corresponding to the vibration modes of the composite beam with a viscoelastic layer. Eventually, the loss factor of FDM composites was calculated from the equation given in ASTM E756-05 standards.

3. Results and Discussion

3.1 Density Measurement

Figure 3 shows the average density value of FDMs with different kenaf fiber loadings. With the increase of kenaf fiber loading, the density of FDM gradually decreases. FDM without kenaf fiber has the highest density (1.482 g/cm^3) while the FDM with 15 wt% of kenaf fiber has the lowest density (1.402 g/cm^3). The reduction in density compared to neat FDM is about 5.4% by adding of 15 wt% of kenaf fiber. Since the mass is directly proportional to density, hence the density of FDM is also decreased.

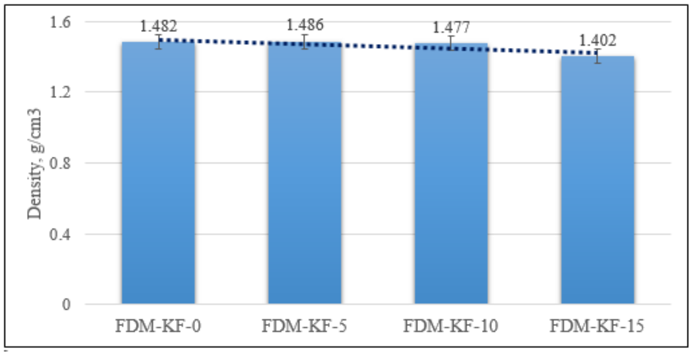

Fig. 3. Average density value of FDMs with different kenaf fiber loadings

3.2 Heat Resistance Test

In this test, optical microscope was used to identify the interface condition between the damping material and mild steel substrate. Figure 4 shows the interface conditions of FDMs with 0 and 15% kenaf fiber loadings) before and after 50 thermal cycles at 40 °C. All FDM samples showed good interface conditions without any crack or delamination after experiencing 50 thermal cycles under 40 °C. The high thermal stability exhibited by FDM composites are resulted from asphalt matrix. According to International Programme on Chemical Safety (IPCS), the softening temperature of asphalt is in the range of 46 °C to 57 °C from which it can be inferred that the physical performance of FDMs may not experience any significant changes when the ambient temperature is below its softening temperature.

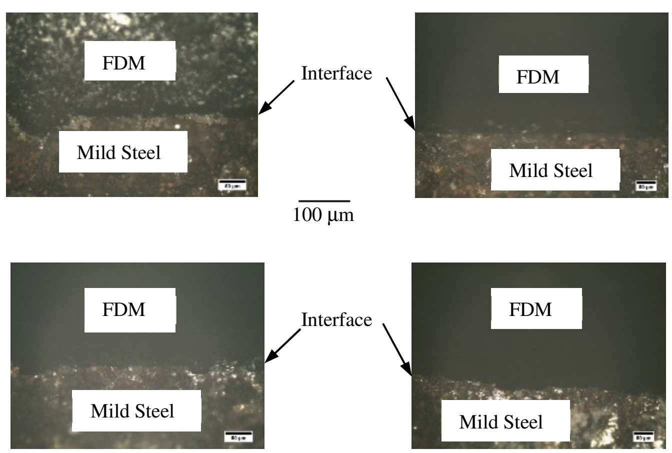

Fig. 4. Interface condition of FDM with (a) 0% kenaf before, (b) 0% kenaf after, (c) 15% kenaf before and (d) 15% kenaf after 50 thermal cycles at 40 °C

3.3 Thermogravimetric Analysis (TGA)

TGA curves of FDMs with different kenaf fiber loadings are shown in Figure 5, where two major weigh loss stages are observed. The first mass loss stage occurred at around 425 °C which may due to the thermal degradation of kenaf fiber. The presence of kenaf fiber greatly accelerated the mass loss during the first volatilization of asphalt as the 15 % kenaf fiber sample has the maximum weight loss. The second mass loss occurs at the range of 725-800 ºC which may attribute to the volatilization of light asphalt components such as saturated, aromatic and decomposition of asphaltene [13].

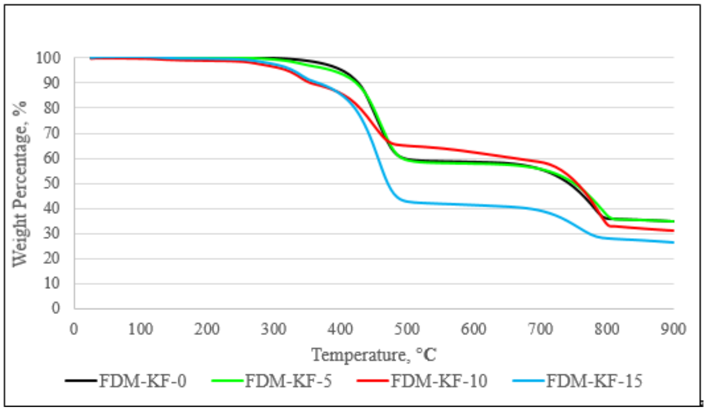

Fig. 5. TGA for FDMs with different kenaf fiber loadings

3.4 Dynamic Mechanical Analysis (DMA)

The storage modulus and loss modulus were analysed by dynamic mechanical analyser. The storage modulus and loss modulus obtained from DMA are presented in Figure 6 of FDM for different kenaf fiber loadings. For any sample, the storage modulus decreases as the temperature increases which indicates the transition of minimum elastic nature to decreasing viscosity [14].

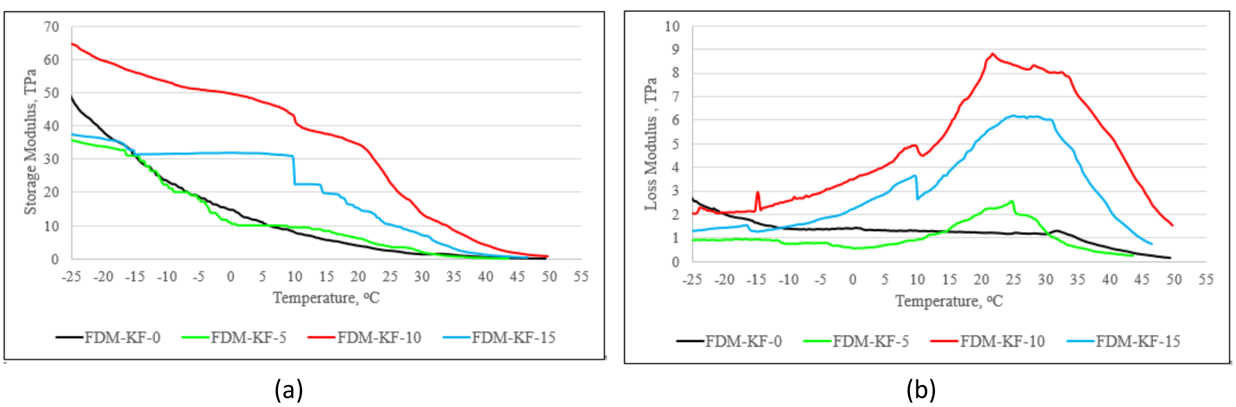

Fig. 6. Function of (a) storage modulus and (b) loss modulus with temperature of FDMs with different kenaf fiber loadings

FDM-KF-0 showed the lowest storage modulus as compared to other samples. The storage modulus increases as the fiber loading increases from 0 to 10% at any temperature. However, a decrease in storage modulus is observed on FDM with 15% fiber. Similar trend was also observed by Pothan [8]. This may occur due to the presence of 15% fiber loading made the matrix become more viscous under dynamic loading as after incorporating certain amount, higher kenaf fiber loading may susceptible to lower wetting of the fiber by asphalt matrix.

For any sample loss modulus goes up as the temperature increases and reaches to a maximum value afterwards the value drops as the temperature increases. The loss modulus increases with the increase in fiber loading in a system. This may be due to the increase in fiber loading creating more interfaces between fiber and matrix where frictional damping occurred and eventually more energy is dissipated in the form of heat during the damping process. FDM without kenaf fiber showed the lowest value of loss modulus while FDM with 10% of kenaf fiber loading obtained the highest value among all the FDM samples. However, FDM with 15% kenaf fiber showed lower loss modulus as compared to FDM with 10% kenaf fiber loading. It can be inferred that at low fiber fraction (0-10%), the loss modulus is increased as the increase in fiber/matrix interface. Clustering of kenaf fibers at a higher weight percentage (15 %) may cause a decrease in its loss modulus.

3.5 Oberst Beam Method Testing (OBM)

The material loss factor of FDM composites were determined through Oberst beam method at a frequency range of 1 – 1200 Hz. Figure 7 show the comparison of frequency response functions (FRF) obtained from flat mild steel and FDM with 0, 5, 10 and 15% kenaf fiber loading respectively. From Figure 9, damping of the flat mild steel was observed in the range of around 100 – 1000 Hz which is also the range of interest in automotive application. Besides that, the damping treatment had a positive effect on the damping mechanism of the mild steel. The reduction of amplitude of mild steel and mild steel with FDM composites are tabulated in Table 2. From Table 2, it showed that the maximum peak reduction increases with the increase of kenaf weight and it is about 83.3% for 10% kenaf fiber and the peak reduction value goes down to 57.7% for 15% fiber loading. The decrease in amplitude of damping peaks indicated that more energy was being dissipated during the damping mechanism.

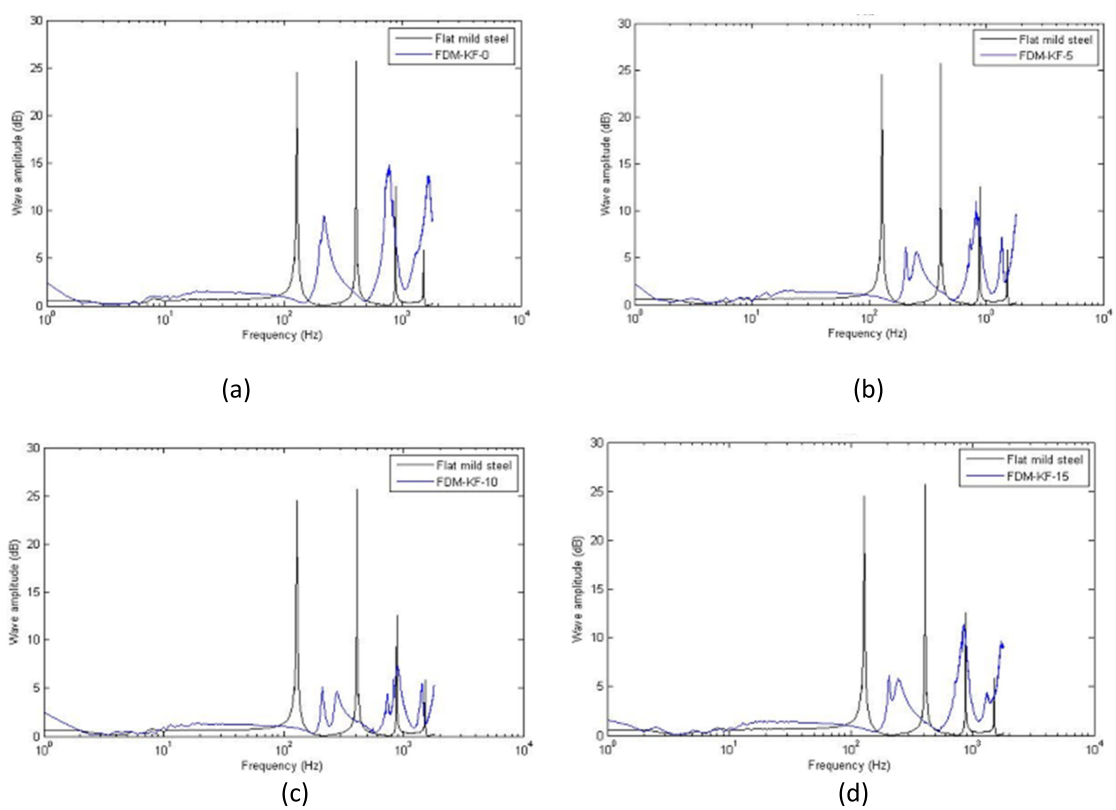

Fig. 7. Comparison of mode shapes of amplitude vs. natural frequency response for flat mild steel and FDMs with (a) 0%, (b) 5%, (c) 10% and (d) 15% kenaf fiber loadings

Table 2
Reduction in peak amplitude compared to mild steel

	1st peak (dB)	Reduction (%)	2nd peak (dB)	Reduction (%)
Mild steel	24	0	26	0
FDM-KF-0	9	62.5	15	42.3
FDM-KF-5	5	79.2	10	61.5
FDM-KF-10	4	83.3	7	73
FDM-KF-15	5	79.2	11	57.7

Figure 8 shows the comparison of material loss factor for FDMs with different kenaf fiber loading. The base composite (0% kenaf) has a loss factor of 0.08 with a natural frequency of 200 Hz. It was observed that the loss factor was 0.11 and increased by 37.5% for 10 wt% kenaf composite when compared to base composite. This may be due to the composites possessing high stiffness on account of the high modulus of kenaf fibers and its uniform distribution which results in a good bonding between the reinforcement and the matrix. In addition a large interfacial area between the asphalt and kenaf fiber increases the modulus value as well as the energy dissipating interface [15].

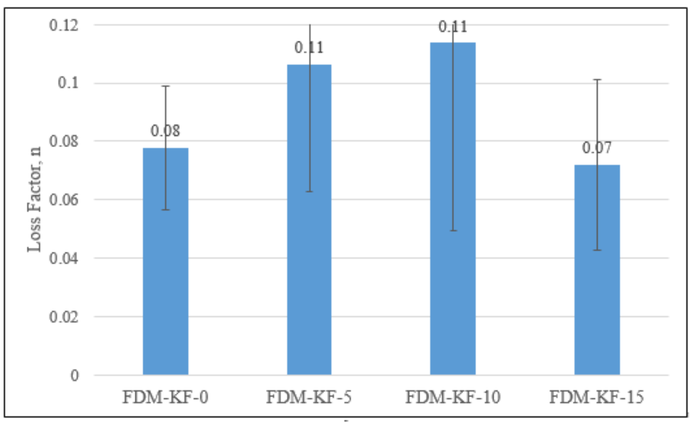

Fig. 8. Comparison of material loss factor between FDM with different kenaf fiber loadings

The composite with a high concentration of 15 wt% kenaf fiber composite shows a decrease in loss factor. Agglomeration and non-uniform distribution of kenaf fibers at a higher weight percentage causes a decrease in its loss factor.

5. Conclusions

The physical properties and damping behaviors of the asphalt matrix and calcium carbonate and kenaf fiber reinforced composites were studied. Based on the experimental study, the following conclusions were made:

- Both the density and weight loss due to thermal degradation temperature decrease with the incorporation of kenaf fibers
- Increase in fiber loading has no significant effect on various thermal cycles carried out at the

softening temperature of asphalt (40°C).

- The effect of kenaf fiber reinforcement increases the natural frequency and damping effect when compared with base composite. The 10 wt% kenaf fiber reinforcement asphalt composite has high damping ability.

This study indicates that incorporation of kenaf fibers could potentially be used in asphalt for automotive damping materials with superior damping behavior at wider frequency.

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