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VIBRATION TRANSMISSIBILITY STUDY OF HIGH DENSITY SOLID WASTE BIOPOLYMER FOAM

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ABSTRACT

Waste cooking oils are problematic disposal especially in the developed countries. In this paper, waste cooking oil is used as raw material to produce foam. The purpose of the study is to develop the high density solid biopolymer foam (HDB) by using hot compression moulding technique based on flexible and rigid crosslinking agents. Physical properties such as Scanning Electron Microscope (SEM) and vibration characteristics have been studied via vibration transmissibility test according to ASTM D3580-95 standard. By using the linear vibration theory with single degree of freedom, the resonance frequency of vibration transmissibility and damping ratios of HDB foam at variation excitation are acquired. The results show that HDB flexible foam gives higher damping ratio to absorb vibration. The different thicknesses were examined during the fabrication of (HDB) to measure the vibration property. The decreasing of HDB flexible foam thickness gives increasing of the damping ratio up to 36%.

Keywords: High density solid; Foam; Vibration transmissibility test

INTRODUCTION

In Malaysia, an option for disposing of used cooking oil is limited. Disposal is difficult because used cooking oil is usually in a liquid or semi solid form and the solid waste regulations restrict the disposal of liquids in landfills (Solid Waste Program, 2012). Waste cooking oil must not be poured down drains or sewers because this inevitably leads to blockages and odour or vermin problems and may also pollute watercourses leading to problems for wildlife (Solid Waste Program, 2012; Food Standard Agency, 2004). Other disposal methods can also be problematic. Open burning of used cooking oil causes black smoke, which is prohibited (Food Standard Agency, 2004).

In this paper, biopolymer foams were produced by using waste cooking oil monomer. In previous research, flexible polyurethane foams produced from the polycondensation of polyols with isocyanate, are formed by open cells and high gas permeability, low density and limited mechanical strength (Saunders, 1962; Ulrich, 1983). Due to this situation, the waste biopolymer foam was used to be fabricated into (HDB) by using hot compression technique. The other researcher was using liquid moulding techniques to fabricate metal foam composite sandwich structure is gaining recognition for high performance applications in a variety of commercial and defence industries (Vaidya et al., 2006). Furthermore, mechanical and physical properties of foam are examined from previous study, the ability of polymeric foam to absorb energy of vibration stands behind a wide variety application in an automotive industry, packaging and transportation of fragile goods (Zaretsky et al., 2012).

Vibration will relate to the damping property but in this case was observed capability of vibration absorption on the HDB. The dynamic properties such as stiffness and damping of the material resolve the level of the transmission of vibration through the material (Rivin, 2003). In most application, a high damping capacity, expressed by damping ratio is desired (Vaidya et al., 2006). Our study will provide further understanding of the vibration characteristic, the morphological and physical properties of the HDB based on rigid and flexible crosslinking agents.

EXPERIMENTAL

Raw materials

The raw material for the HDB fabrication are: biopolymer based on waste cooking oil monomer (Anika, 2008; Anika, 2009a; Anika, 2009b), rigid isocyanate and flexible isocyanate.

Foam production

The polyol based waste cooking oil monomer and isocyanate were stirred with a PHILIPS Multiple Speeds Handmixer in a cup for 15 seconds (Anika, 2009c). The mixtures were then immediately cast into open mould before the foam is expanded out. It was left for 12 hours to reach cured (Anika, 2010).

Waste granulate biopolymer preparation

The biopolymer foam was cut into small cube size and grained using grinding machine and sieved to have proximate by 0.08 mm in size.

Hot compression

160 g waste granulate foam was weighed to fill into the mould with internal core size of 180*180*15 mm to produce HDB. The parameter of the compression machine was set at 90° C of temperature, under 26 tonnes of pressure within 1 hour. Two samples were prepared using this method which is HDB based on rigid and flexible crosslinking agents. Those samples were cut into nine pieces for every sample with dimension of 50*50*6 mm respectively.

Scanning Electron Microscope (SEM)

HDB surfaces were examined by (SEM, JEOL-JSM6380LA). The HDB sample was mounted on the holder using double sided tape and sputter-coated with gold to impart electrical conductivity and reduce charging artifacts (Alonso et al., 2006) by using Auto Fined Coater of JEOL-JFC1600. The operation voltage of the SEM was 10kV with 40 μm magnifier under low vacuum.

Density test

The density test of HDB was conducted by prepared a cube of 10*10*6 mm**.** The weights of the HDB were measured using Mettler Toledo Laboratory Weighing. This test was carried out according to ASTM D3574-08. The densities of HDB were calculated as Eq. (1), where m = mass of foam and v = volume of foam. The average density of a HDB of four samples was tabulated in Table 1.

Table 1. Physical and mechanical properties of HDB

HDB sample	Mass (g)	Thickness (mm)	Density (g/cm^3)
Flexible (F)	0.7605	6.10	1.2467
Rigid (R)	0.7540	6.35	1.1874

$$\text{Density, } \rho = m/v \tag{1}$$

Vibration transmissibility test

Vibration transmissibility test of HDB was measured by using HDB foam system as shown in Figure 1. A *UCON vt-9008* data acquisition system analysis package (*VSC* software) was used to make the measurements. It was performed according ASTM D3580-95 standard test method for vibration testing (vertical linear motion) (Wong and Schueneman, 1997). Figure 1 illustrates of HDB foam system. Four pieces of flexible HDB foam and four pieces of rigid HDB foam were prepared in 50*50*6 mm to run the vibration transmissibility. There are six HDB samples were examined with three difference thickness for both flexible and rigid HDB. Transmissibility tests were generated at various base excitation levels that is (i) 1 mm and 1.5 mm, and (ii) 0.1 g and 0.15 g in frequency range of 15-23 Hz and 18-26 Hz respectively. Only two blocks that is 482.95 g were loaded to the moveable top plate and locked on the sliding top plate.

Two *Kistler* accelerometers were initially attached on base and sliding top plates for measured the vibration amplitude of base plate (input) and response of mass (output) to the base excitation. In this system, a vertical amplitude, y(t) was initially given at the shaking table but the total amplitude, x(t) received by cylindrical blocks (mass) was noticed from the moveable top plate. Due to the static creep exhibited by the HDB foam, the whole system was then allowed for 30 minutes to reach a static equilibrium before the vibration test began. The vibration test was started by the start button in the VCS software and automatically stopped after reaching the maximum frequency for both excitations. There were a total three trials for every HDB foam sample.

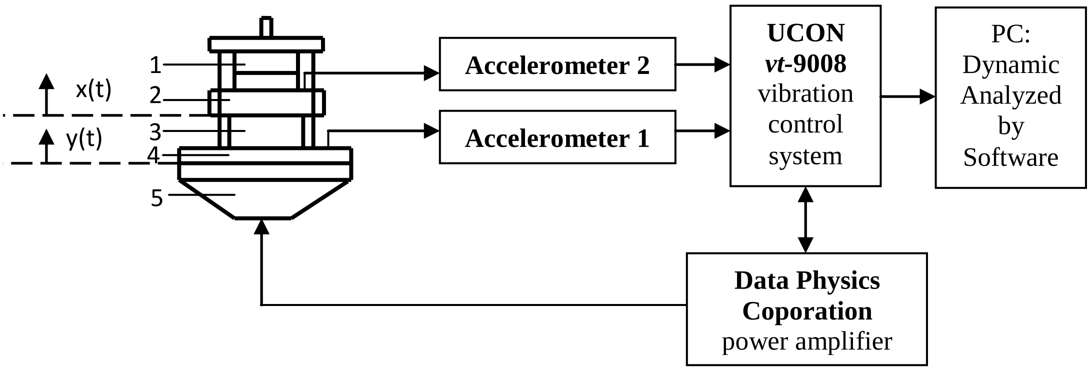

Figure 1. Schematic diagram of HDB foam system: (1) load; (2) sliding top plate; (3) HDB foam; (4) base plate; (5) shaker

Table 2. Sandwich layer of HDB in vibration test

HDB sample	FF	FFF	FFFF	RR	RRR	RRRR
Thickness (mm)	12.2	18.3	24.4	12.7	19.05	25.4

RESULTS AND DISCUSSION

Density analysis

Density is related to the mass of the waste granulates HDB. The density of fabricated HDB foams shall be similar with each other since the mass of waste granulates is 160g. It is well known that the higher the density, the higher the weight of HDB obtained (Thomson, 1993). Based on the Figure 2, the densities of HDB flexible are higher than densities of HDB rigid due to the porosity structure. As mentioned from previous research (Dai et al., 2005), higher cell density can offers better damping property.

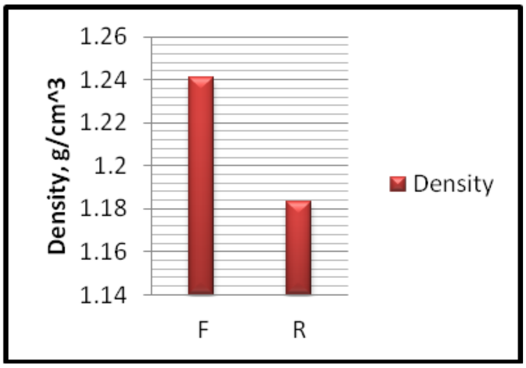

Figure 2. Density results for flexible and rigid samples

Microscopy

In this study, the morphologies of HDB surface were investigated. The SEM images of the surfaces is refer to Figure 3(a) and Figure 3(b). The fabricated of HDB samples shows larger pores with compact were found on flexible. Meanwhile, rigid HDB has less small pores but pluffy in appearance. The structure morphologies according to the SEM results were influence the vibration transmissibility on material.

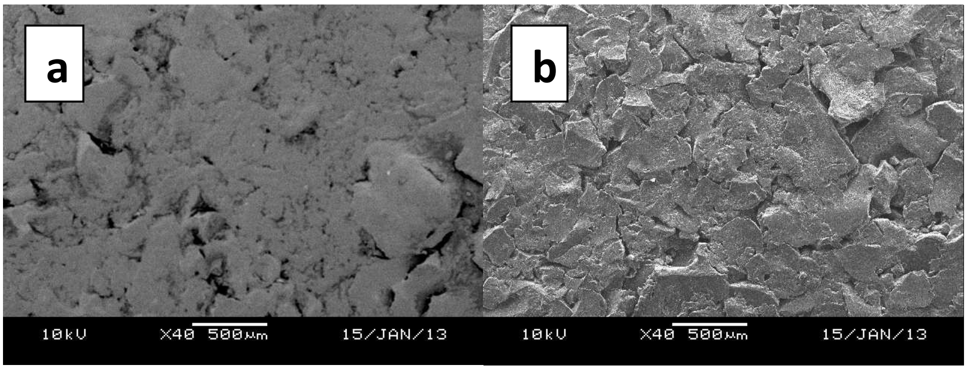

Figure 3. SEM images of HDB foam; a) flexible; b) rigid

Vibration analysis

The results of vibration transmissibility was plotted and discussed in transmissibility versus frequency as referred in Figure 4 to Figure 7. The experimental results showed that when the thickness increases, the resonance peak will increase except in Figure 6(b) and Figure 7(b). From the results, it was observed that when the base excitation increased from 1 mm to 1.5 mm (or 0.1 g to 0.15 g), the resonance and attenuation frequency will shift to the lower values as well as resonance peak but sometime fluctuating data found. This is actually caused by the decrease of the damping when increased the base excitation in vibration testing in high dense solid.

However, the increment of resonance peak was found because of damping reduction obtained in HDB foam system (Inman, 2001). The shifts of resonance frequency toward higher value are occurred when the thickness of HDB foam decrease in systems, although some fluctuating data observed. Among all, system inserted with HDB FF and RR foam achieved the highest resonance frequency during the transmissibility test but the situation was not occurred in Figure 5(a) and Figure 6(b). It can be observed that, the resonance frequencies for HDB FF are 21.39 Hz for 1 mm, 18.51 Hz for 1.5 mm, 24.27 Hz for 0.1 g and 24.11 Hz for 0.15 g. According to the results obtained, the resonance frequencies of HDB RR are 21.31 Hz for 1mm, 18.49 Hz for 1.5 mm, 24.27 Hz for 0.1 g and 23.87 Hz for 0.15 g. The increased of resonance frequency in HDB foam system according to the thickness decrement of HDB inserted may due to the slow and weak response into the system. During the transmissibility, some of the amplitudes (vibrations) were absorbed by HDB foam due to its damping effects. Some of them were dissipated due to frictional losses occurred in uniaxial motion of movable top plate (White et al., 2000).

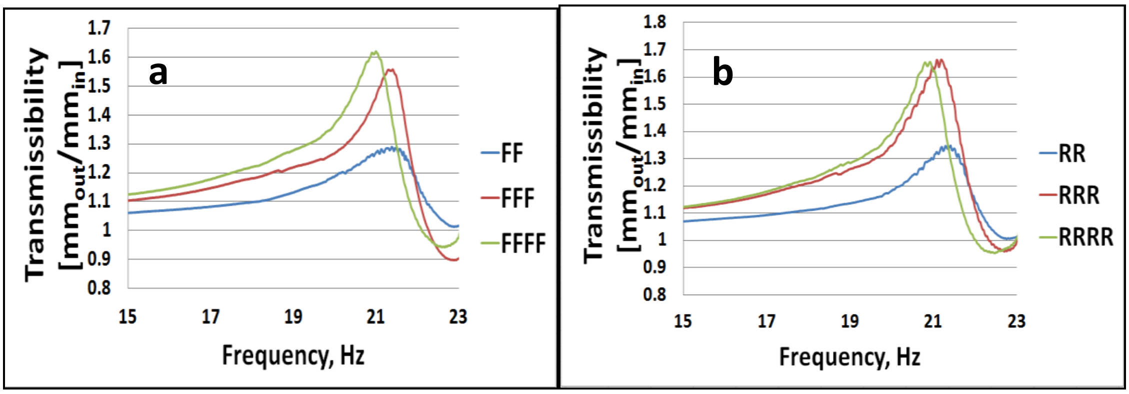

Figure 4. Displacement transmissibility from base to moveable top plate at 1mm base excitation; (a) HDB flexible and (b) HDB rigid

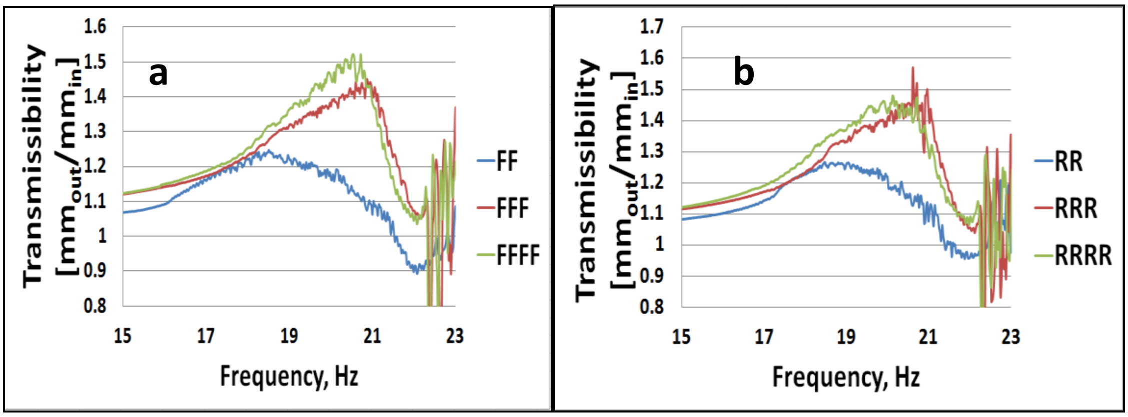

Figure 5. Displacement transmissibility from base to moveable top plate at 1.5mm base excitation; (a) HDB flexible and (b) HDB rigid

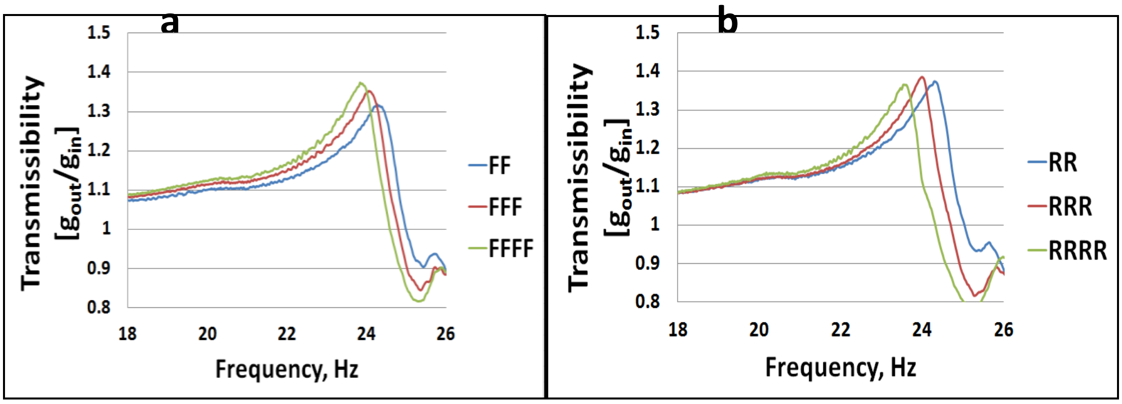

Figure 6. Acceleration transmissibility from base to moveable top plate at 0.1g base excitation; (a) HDB flexible and (b) HDB rigid

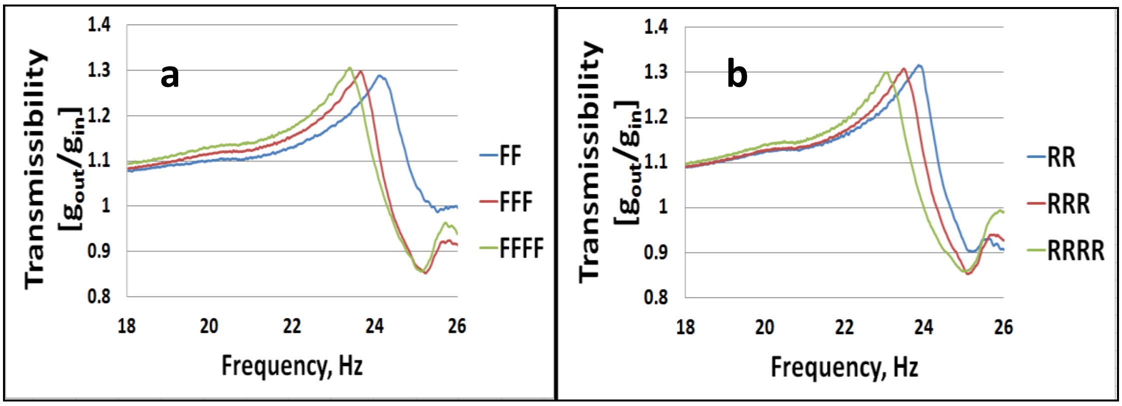

Figure 7. Acceleration transmissibility from base to moveable top plate at 0.15g base excitation; (a) HDB flexible and (b) HDB rigid

Damping analysis

For the vibration test system in Figure 1, the mass block on the HDB foam specimen system may be idealized as the linear single degree of freedom (SDOF) system as shown in Figure 8. It was observed that similar modelling was used in studies of (White et al., 2000; Joshi et al., 2010).

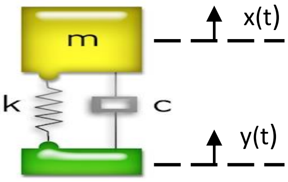

Figure 8. The HDB foam system was modelled as a mass-spring damper system

SDOF with viscous damping and the vibration transmissibility T_r would be described as

$$T_r = \sqrt{\frac{1+(2\xi\lambda)^2}{(1-\lambda^2)^2+(2\xi\lambda)^2}} \qquad (2)$$

where λ stands for frequency ratio ($\lambda = f/f_r$), f is excitation frequency of vibration table, f_r is resonance frequency of HDB foam, and ζ represents damping ratio. It is evident that vibration transmissibility has a close relationship with frequency ratio and damping ratio (Guo et al., 2010). In this case, the frequency ratio (λ) is equal to 1. Hence, the transmissibility shown in Eq. (2) is used to calculate the total damping ratio (ζ_{total}) that occurred in HDB system, as the parameter λ and T_r at peak are known. The damping ratio (ζ) may be derived from Eq. (2) and written as

$$\xi = \frac{1}{2}\sqrt{\frac{1}{T_r^2 - 1}} \qquad (3)$$

Table 3 present the averaged damping ratio of HDB foams calculated based on measurement data obtained from transmissibility test. It is assumed that the damping effects generated in HDB foam system are caused by (i) frictional losses from bearings during vertical movement of top plate, and (ii) the HDB foam inserted. Based on the results obtained, the total damping ratio (ζ_{total}) is decreased when the thickness of HDB foam increased except RRRR HDB foam as shown in Table 3(b). This is caused by HDB rigid foam is a hard and brittle material. Therefore, when the transmitted occur in the system, the response and damping is not consistent due to the characteristics of material. In this damping property study, HDB flexible foams show that they could provide higher damping than HDB rigid foam, although there are some variations occurred.

The damping ratio calculated also revealed that FF HDB foam have good vibration damping which are 0.61 for displacement at 1mm and 0.67 at 1.5 mm. Besides, the damping ratio for acceleration at 0.1 g is 0.58 and at 0.15 g is 0.62. From this study, decreasing the HDB flexible foam thickness increased the damping ratio up to 36%.

Table 3(a). Damping ratio of HDB flexible foams obtained by data measured

Index	Damping in HDB foam system (ζ_{total})			
	Displacement		**Acceleration**	
Base Excitation	**1 mm**	**1.5 mm**	**0.l g**	**0.15 g**
FF	0.61	0.67	0.58	0.62
FFF	0.42	0.48	0.55	0.61
FFFF	0.39	0.44	0.53	0.59

Table 3(b). Damping ratio of HDB rigid foams obtained by data measured

Index	Damping in HDB foam system (ζ_{total})			
	Displacement		**Acceleration**	
Base Excitation	**1 mm**	**1.5 mm**	**0.l g**	**0.15 g**
RR	0.56	0.64	0.54	0.58
RRR	0.38	0.44	0.52	0.59
RRRR	0.38	0.46	0.54	0.60

CONCLUSION

As the conclusion, the capability of the HDB flexible to absorb the vibration is greater than HDB rigid and HDB flexible give higher damping than HDB rigid. Two layers of HDB gives better damping ratio than three and four layers of HDB. The difference thickness of HDB either flexible or rigid has different resonance peak and resonance frequency. There is critical frequency at which the vibration transmissibility is high and above the critical frequency. The vibration transmissibility drops and is smaller than 1 except the rigid HDB. It can be summarized from the mass, density and characteristic of the HDB structure as shown in SEM that influence the vibration absorption of the system. This HDB can be applying in any application especially in automotive field and manufacturing packaging.

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