

Improvement of acoustical characteristics : wideband bamboo based polymer composite

M Farid, A Purniawan, A Rasyida, M Ramadhani, S Komariyah

Department of Materials and Metallurgical Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.

E-mail : mofaredo@gmail.com

Abstract. Environmental friendly and comfortable materials are desirable for applications in the automobile interior. The objective of this research was to examine and develop bamboo based polymer composites applied to the sound absorption materials of automobile door panels. Morphological analysis of the polyurethane/bamboo powder composite materials was carried out using scanning electron microscope to reveal the microscopic material behavior and followed by the FTIR and TGA testing. The finding demonstrated that this acoustical polymer composite materials provided a potential wideband sound absorption material. The range of frequency can be controlled between 500 and 4000 Hz with an average of sound absorption coefficient around 0.411 and it met to the door panels criteria.

1. Introduction

The natural based composite material was widely used as sound absorption materials. They are used as noise absorption materials in offices, residential and industrial areas. Toyoda *et al.*, (2017) [1] investigated sound absorption enhancement with the wide-band frequency using material which was prepared by adding a filler to the cylindrical space microperforated panels absorbers (CMSAs) and rectangular panels space microperforated absorbers (RMSAs).

Mati-Bauoche *et al.*, (2016) [2] investigated the relationship between the sound absorption properties and dead-end pores or clusters. Park (2013)[3] investigated the acoustic resonator related to the micro-perforated panel absorber. Sanada and Tanaka [4] stated that the flexible panel was needed to expand the range of the sound absorption materials. Wideband sound absorption materials is one of three type of sound absorption materials. Bamboo have been developed by Koizumi and Farid as a potential natural fiber component of the sound absorption material. Koizumi *et al.* [5] has developed an acoustic material derived from polymer composite / bamboo fiber and reported that the fiber diameter reduction effect on the increase in sound absorption coefficient values. Farid *et al.* [6] studied sound absorption coefficient of composite polyester / bamboo fiber. The sound absorption coefficient reached 0.97 at a frequency of 1000 Hz.

There are various types of sound absorption materials, including the wideband type sound absorption material which is a challenge to develop it. This study focuses on obtaining a wideband type sound absorption materials by developing a composite materials based on natural fibers and polymers that meet product standards.



2. Materials and Method

The bamboo used was *dendrocalamus asper* (bambu betung). This bamboo was grown in East Java and the diameter was 10 cm. Based on the Dransfield' experimentation, *dendrocalamus asper* had a moisture content of 55%, air-dry moisture content of 15%, holoselulosa content of 53%, 19% pentosan, lignin 25% and ash 3%. NaOH were used to treat the bamboo fiber. The variable components consisting of bamboo powder and polyurethane composition. The first variable were 5% of bamboo powder, 95% of polyurethane (95% PU), the second variables were 10 % of bamboo powder, 90 % of polyurethane (90% PU) and 15 % of bamboo powder, 85% of polyurethane (85% PU). The specimen was characterized using scanning electron microscope. Sieving process needed 3 shifter tools which had a size of 450, 244 and 148 μm . This research used a fiber size less than 148 μm . Polyurethane was prepared by mixing 70% of polyphenyl isocyanate and 30% of polypropylene glycol. Composite manufacturing process used blending method in which the polyurethane and bamboo powder had the same composition with total mass for absorption test 25 g. Finally, the ingredients were mixed and stirred for 60 s before it was poured into mold and deposited for 24 h. FTIR test was used to analyze functional groups. It offered quantitative and qualitative analysis for organic and inorganic samples. FTIR identifies chemical bond in a molecule by producing an infrared absorption spectrum and it was an effective analytical instrument for detecting functional groups and characterizing covalent bonding information. FTIR test was used to analyze functional groups.

Characterization of functional groups of composite were performed using the Thermo Scientific Nicolet iS 10 (Thermo Fisher Scientific, Inc, MA, USA) with a wavelength of 4000-400 cm^{-1} . Specification of FTIR instruments was as follows: Interface: PC USB 2.0. Laser: HeNe. Performance verification: ASTM E1421 to meet customer ISO/GLP requirements. Power supply: 100-240 V 50/60 Hz. Spectral range: 7800-350 cm^{-1} optimized, mid-infrared KBr beamsplitter 11000-375 cm^{-1} XT KBr extended range mid-infrared optics. Spectral resolution: Better than 0.4 wavenumber. Meanwhile, surface morphology analysis used Scanning Electron Microscope (SEM) type FEI INSPECT S50. Sound absorption analysis using ASTM E1050 standard was used to determine the ability of the composite to absorb sound.

3. Results and Discussion

The synthesis process of polyurethane was made by mixing polyurethane A and Polyurethane B. Polyurethane A was used for isocyanate and polyurethane B was used for polyol. The result indicates that there was stretching vibrations bond $\text{O}=\text{C}=\text{N}$ with wave length of 2240 cm^{-1} in Polyurethane and absorption bands with wavelength 1519 cm^{-1} for $-\text{C}=\text{C}-$ bond and wave length of 1100 cm^{-1} for $\text{C}-\text{C}-\text{C}$ bond. This is shown in Figure 1.

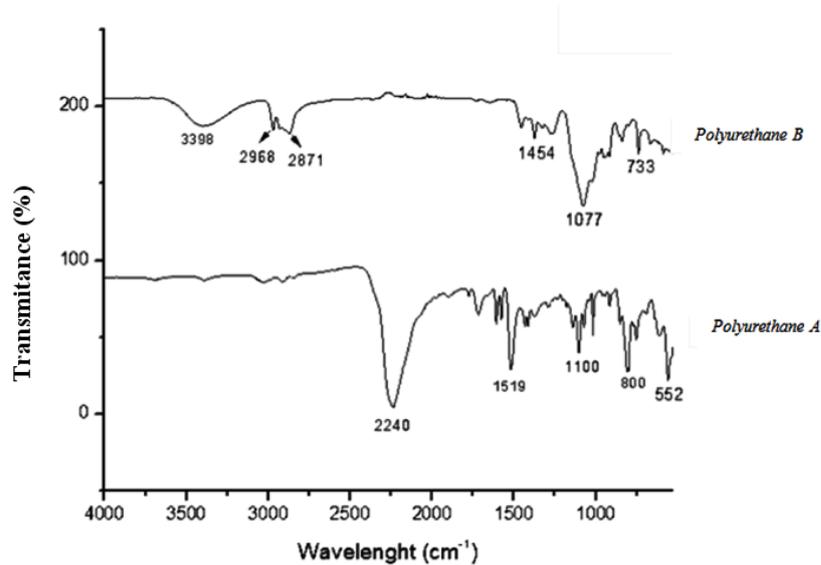


Figure 1. The result of FTIR analysis for polyurethane A and polyurethane B

This bond shows that polyurethane A was an *isocyanate*. Meanwhile, the absorption wave for double bond CH shows 800 cm^{-1} and stretching vibration with C=CH isocyanate bond shows wave length of 552 cm^{-1} . Therefore, we can conclude that *polyurethane A* was a type of polyphenyl Isocyanate. Polyurethane B graphic shows that there was stretching vibration for O-H bond with wave length of 3398 cm^{-1} . which means that polyurethane B was polyol. There was an obvious absorption energy for CH_3 on wave length of 1454 and 2968 cm^{-1} . The absorption peak for CH_2 appears on wave length of 733 and 2871 cm^{-1} . At the same time, the stretching absorption for CH_2OH was 1077 cm^{-1} ; thus, polyol was known as polypropylene glycol.

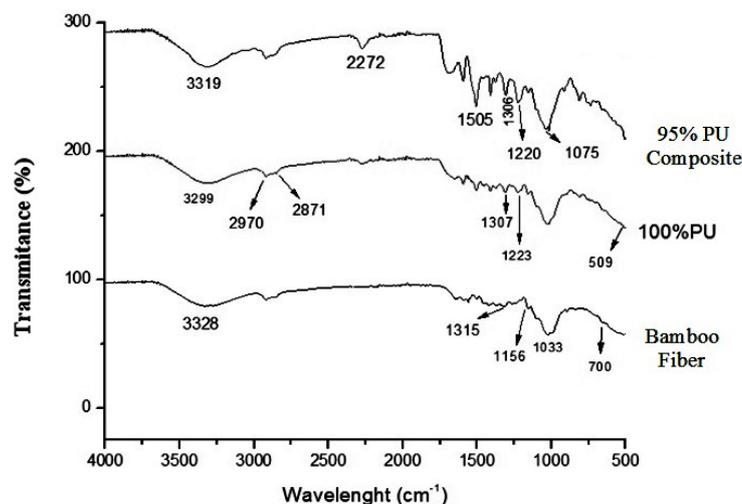


Figure 2. The Result of FTIR analysis for Bamboo Fiber, 100%PU and 95%PU composite.

FTIR test was performed to identify the presence of lignin, $-\text{OCH}_3$ groups is a part of the lignin and it had wavelength of $2860\text{--}3000\text{ cm}^{-1}$. Figure 2 shows that there was no peak on wavelength $2860\text{--}3000\text{ cm}^{-1}$; hence, there was no lignin on bamboo fiber after alkaline treatment. Composite graphic with 100% PU on wavelength 3299 cm^{-1} identified stretching vibration of N—H and on wavelength 1233 cm^{-1} which means there is absorption of C—N .

Figure 2 shows the test results of FTIR bamboo fiber after alkali treatment. Alkali was intended to remove the lignin content of the bamboo; from this figure it was evaluated that there was an absence of the group $-\text{OCH}_3$ with wavelength $2860\text{--}3000\text{ cm}^{-1}$ which shows a part of the lignin. Moreover, the addition of 5% bamboo did not significantly change the structure of pristine polyurethane.

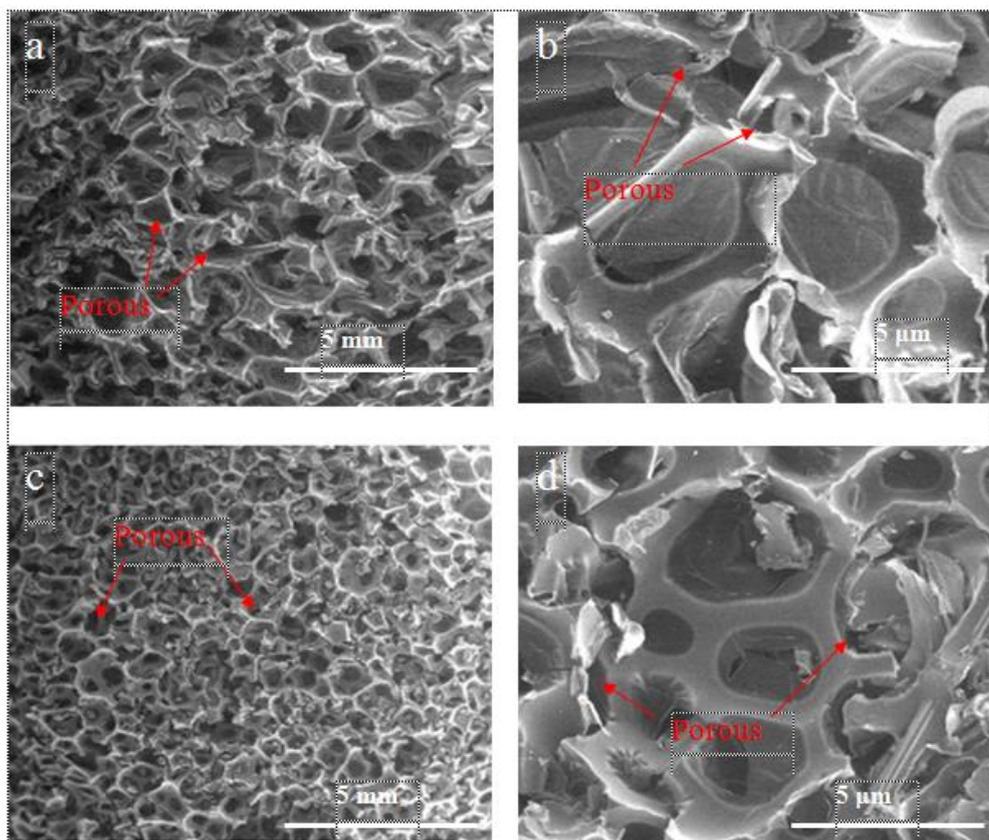


Figure 3. SEM images of 100% PU with 50x (a) and 250x (b) of magnifications and its composite (85% PU) with 50x (c) and 250x (d) of magnifications.

Figure 3 shows the SEM micrographs of the PU and its composites, revealing that there was interconnected porosity. The white part corresponded to the pore shape whereas the dark part was related to the open holes. This kind of porosity was an important parameter to develop the acoustic behaviour [8]. However, we can evaluate that there were differences between the size and the

distribution of the pore cell sizes. It was assumed that the addition of 15% bamboo fillers as reinforced can slightly alter the foam size distribution.

Typical porous cell diameter was obtained by inspecting visually the diameter of at least 20 porous cells on the surface of the foams [8]. Figure 3 (a) and (b) shows that the cell size became larger from 0.46 mm to 1.30 mm in diameter. Figure.3 (c) and (d) shows that the amount of porous cells more than 20 on the surface of the foams and it became larger from 0.48 to 1.66 mm in diameter.

The table shows mass of the specimen at a temperature of 250 °C. At this temperature, there was a little mass reduction. Even for pure PU, the mass increased to 100.5109. While the specimen with 5% of fiber, the mass decreased into 98.56787 and specimens with 10% of fiber, the mass degraded into 98.88169. Meanwhile, the specimens with 15% of fibre was 97.22951. The average working temperature stability of this material is in the range of 100 to 200 °C.

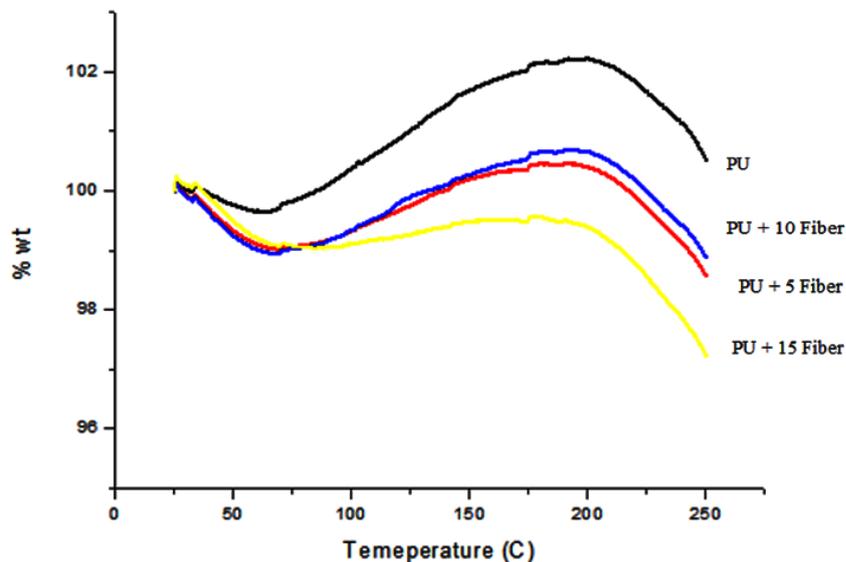


Figure 4. TGA of 100% PU, 95% PU, 90% PU, and 85% PU

The Figure 4 shows mass of the specimen at a temperature of 250 °C. At this temperature, there was a little mass reduction. Even for pure PU, the mass increased to 100.5109. While the specimen with 5% of fiber, the mass decreased into 98.56787 and specimens with 10% of fiber, the mass degraded into 98.88169. Meanwhile, the specimens with 15% of fibre was 97.22951. The average working temperature stability of this material is in the range of 100 to 200 °C.

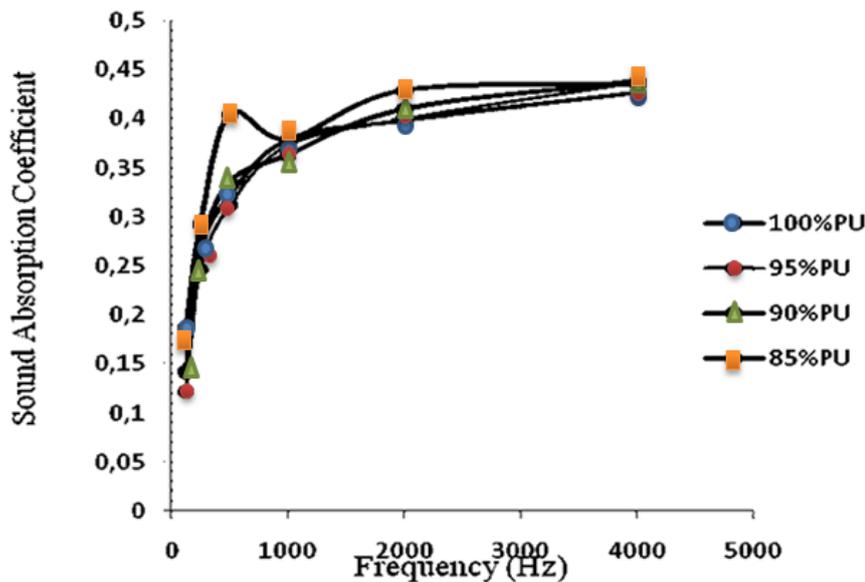


Figure 5. Sound absorption coefficient of 100% PU, 95% PU, 90% PU, and 85% PU

Figure 5 shows that the composite 85% PU had a sound absorption coefficient of 0.404, 0.379, 0.428, and 0.434 for each frequency of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. It was very interesting because the result was a relatively stable value. Thus, it can be concluded that with a composition of 85% of PU and 148-450 microns of bamboo powder it was obtained an average sound absorption coefficient stability 0.411. This value meets the standard criteria for door panel.

Referring to the research of Zhang (2012), Verdejo *et al.*, (2009) and Nordgren (2010), generally characteristic of polyurethane based acoustical composite material relied on aspects of cell size foam, vibroacoustic energy, the phenomenon of viscoelastic and viscoacoustic, air flow, sound pressure, kinetic energy, elasticity, permeability, flow-resistivity, etc. [8-10]. Generally, the sound absorption coefficient of the porous material affected by porous cell size and structure. Polyurethane foam having a larger cell size has a sound absorption coefficient greater than the PU which has a smaller cell size at a certain frequency. Vibro-acoustic energy occurred both in the pores and solid frame of the material [8]. The large foam cell produced cell wall deformation larger, so more sound energy could be converted into kinetic energy [10].

4. Conclusion

The morphology, thermal stability, sound absorption coefficient, and functional groups of PU/bamboo fiber composite have been studied. Modification of long fibers reinforcement into a fine powder in the micron scale and the selection of the specific composition of polyurethane as a composite matrix provided a way to obtain wideband sound absorption materials. The addition of bamboo powder can

slightly alter the foam size distribution. Formation of cells was closed cell. The addition of filler led to an increase in cell thickness. This contributed to the improvement of the sound absorption coefficient. The PU/Bamboo powder composite materials had a sound absorption coefficient of 0.411 and could be used in the frequency range from 500 to 4000 Hz; thus, this was in accordance with the criteria on the interior door panel of the car.

Acknowledgments

The Authors would like to express their gratitude to Department of Materials and Metallurgical Engineering ITS for the financial support.

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