SOUND-ABSORBING PROPERTIES OF WASTE SCRAPED TIRE RUBBER FIBER REINFORCED POLYVINYL ALCOHOL FILMS AS RUBBER AEROGEL

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Abstract

Poly vinyl alcohol (PVA) based polymers are being widely used in additive manufacturing because of their physical characteristics such as low weight, flexibility, thermally and electrically insulation. The morphological characterization of pure PVA film and scraped tire rubber fiber (STRF) reinforced PVA films were investigated by the digital optical microscope (x1000). The average size of air bubble of PVA film and STRF reinforced PVA films are about 1.9E-8 mm^2 and 7.06E-8 mm^2. The chemical functional group of pure PVA film and 5 w/v%, 10 w/v%, 15 w/v%, 20 w/v% waste scraped tire rubber fiber reinforced PVA films were examined by the Fourier Transform Infrared Spectroscopy (FTIR) in the range of wave number from 4000 to 450 cm^{-1}. The resultant FTIR transmittance spectra were matched with chemical functional group of PVA and scraped tire rubber fiber (STRF). The acoustic absorption coefficient of pure PVA film and waste scraped tire rubber fiber (STRF) reinforced PVA films were investigated in the range of audio frequency 200 Hz to 2 kHz.

Keywords: PVA, scraped tire rubber fiber (STRF), acoustic properties, optical microscope, FTIR, STRF composite PVA films

Introduction

Nowadays PVA based polymers are being widely used in additive manufacturing. Poly (vinyl alcohol) PVA is a water-soluble synthetic polymer. It has the idealized formula $[CH_2CH(OH)]_n$. Polyvinyl alcohol has a melting point of 180 to 190°C. Poly vinyl alcohol is a hydrophilic semi-crystalline polymer produced by polymerization of vinyl acetate to poly vinyl acetate (PVAc), and subsequent hydrolysis of PVAc to PVA. Commercial PVA is available in highly hydrolyzed grades (degree of hydrolysis above 98.5%) and partially hydrolyzed ones (degree of hydrolysis from 80.0 to 98.5%). The content of hydrolysis or the content of acetate groups in PVA affects its chemical properties, solubility and crystal growth ability.

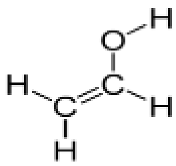

Figure 1 Molecular Structure of Poly vinyl alcohol (PVA)

Polymeric scraped tire rubber fiber (STRF) is one of the byproducts derived from the processing of used vehicle tires. Presently, significant quantities of STRF are generated annually in most developed countries of the world. However, and unfortunately, STRF been an amalgam of crumb rubber, steel and other particles, its reusability has been limited. Hence, STRF is mainly used as a fuel source in kilns or landfilled. Sulfur vulcanization of rubber is the most commonly used chemical process, by which cross-links are formed between rubber polymer chains by heating, thereby enhancing the physical properties of vulcanizes. Thus, as a consequence of vulcanization, a typical tire rubber contains about 1.52–1.64% sulfur and other chemical

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constituents such as 81.2–85.2% carbon, 7.22–7.42% hydrogen, 1.72–2.07% oxygen and 0.31–0.47% nitrogen, nitrogen oxides (NO_x), Sulfur dioxide (SO_2), carbon monoxide (CO) and polycyclic aromatic hydrocarbon (PAH) are emitted during scrap tire combustion. The sulfur gases are also produced during scrap tire pyrolysis. Toxic hydrogen sulfide gas was also observed as a major byproduct of scrap tire pyrolysis. Therefore, to avoid the inherent environmental pollution associated with the combustion of waste car tire rubber, it is imperative that alternative benign and value-added applications for STRF be developed.

By adding the scraped tire rubber fiber (STRF) to the PVA film, the sound absorption, electrically insulation and thermal insulation properties of PVA film can be enhanced because of their good properties such as low weight, flexibility, highly absorption and thermally insulated.

Materials and Experimental Methods

Materials

Poly Vinyl Alcohol (PVA, molecular weight of 186,000 g/mol, Sigma Aldrich, Germany) was purchased and used without further purification. The waste car tire was collected from the car workshop and cleaned to scrap the rubber filament from the waste vulcanized rubber car tire. Deionized water was used in the preparation of the blending PVA films.

Sample Preparation

The waste car tire was collected and washed in water by using iron brush. The scrap tire rubber fibers were scraped from the washed pieces of the waste car tire by the iron brush rotor machine and put the scraped tire rubber fibers into the pure water to separate the rubbers and the iron dust, metal pieces of the tire by the floating method. The floating scraped tire rubber fibers were filtered and dried in the oven at 150°C for 2 hr. Finally, the remaining iron dust in the scraped tire rubber fibers were eliminated by the magnet to get purified scraped tire rubber fiber (STRF).

Preparation of the Waste Scraped Tire Rubber Fibers (STRF) Reinforced (PVA) Films

The 2 g of PVA were dispersed in 10ml of deionized water and was stirred for 20 min at 80°C with 500 rpm to get the transparent and homogeneous 20 w/v% PVA solution. The 20 w/v% PVA solution was poured into the ceramic mold to cast the pure PVA film by solution-casting method and the resultant PVA film was dried at 60 °C in the desiccator to synthesize pure PVA film. The 0.5 g of the scraped tire rubber fiber (STRF) were slightly added into the homogenous 20 w/v% PVA solution and was stirred for 20 min at 80°C with 500rpm. The resultant rubber fiber mixed PVA solution was casted into ceramic mold by the solution casting method to get the 5 w/v%, STRF reinforced PVA film. The 10 w/v% and 15 w/v%, 20 w/v% STRF reinforced PVA films were also prepared by the use of 1 g 1.5 g and 2g of the scraped tire rubber fiber (STRF) as the above solution-casting method. The resultant STRF reinforced PVA films were dried and kept at 60°C in the desiccator. Figure 2 shows sample preparation processes of the scraped tire rubber fiber.

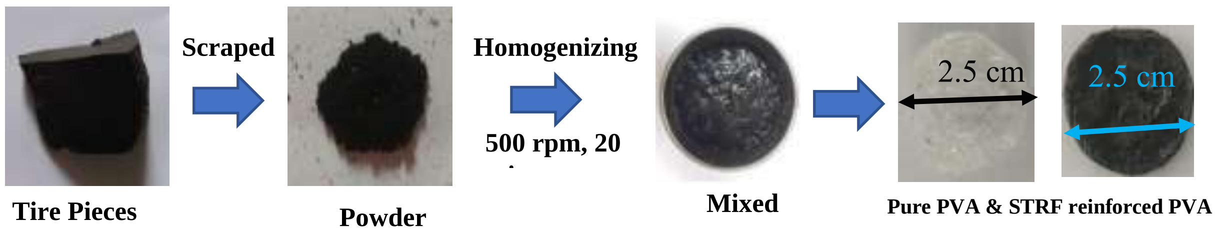

Figure 2. Sample preparation processes of the scraped tire rubber fiber

Morphological Characterizations

The morphological characterization of pure PVA film was investigated by the Transicom Singapore 300 LCD digital microscope (x1000). The average size of air bubble of pure PVA film and STRF reinforced PVA films were examined by the use of the Fiji image analysis software.

Chemical Functional Group Analysis by FTIR Method

The chemical functional group of pure PVA film and 5 w/v%, 10 w/v%, 15 w/v%, and 20 w/v% waste scraped tire rubber fiber reinforced PVA film were examined by the Fourier Transform Infrared Spectroscopy (FTIR). The pure PVA films and the waste scraped tire rubber fiber reinforced PVA films were obtained as 4 mm thickness films and analyzed by the FTIR using Transmittance Mode. FTIR spectra were obtained in the range of wavenumber from 4000 to 450 cm^{-1} using FTIR spectrometer Perkin Elmer, 109976, USA. The FTIR spectra were normalized and major vibration bands were associated with chemical functional groups.

Acoustic Absorption Analysis

The acoustic absorption coefficient of pure PVA film and waste scraped tire rubber fiber (STRF) reinforced PVA films were investigated in the range of audio frequency 200 Hz to 2 kHz by the use of the oscilloscopic analysis. The frequency generator, oscilloscope and sound transmission tube were served to examine the acoustic absorption coefficient of sample PVA and STRF composite PVA films. The acoustic absorption coefficient measurement setup is depicted as in the Figure 3 and 4. The acoustic absorption coefficients of the samples were calculated as the following relation.

$$\alpha = 1 - \frac{I_{\text{Transmission}}}{I_{\text{incident}}} \tag{1}$$

α= acoustic absorption coefficient

I_{incident} = Intensity of incident sound wave, I_0

$I_{\text{Transmission}}$ = Intensity of transmitted sound wave, I

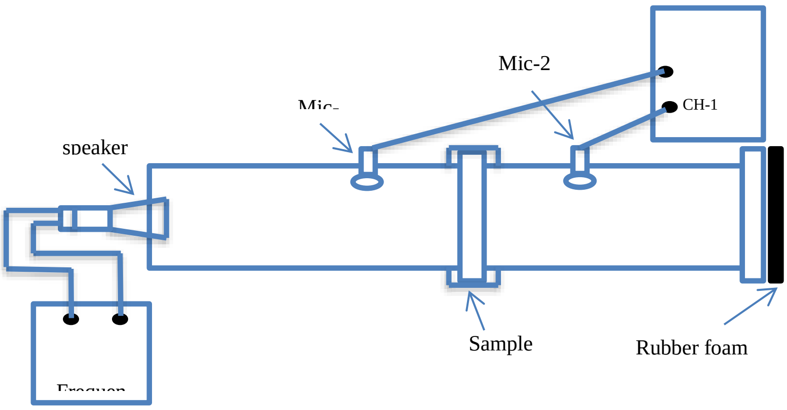

Figure 3. Acoustic absorption coefficient measurement setup

Figure 4. Measurement of Acoustic absorption coefficient

Results and Discussion

The morphological characterization of pure PVA film by the optical microscope shows the roughness surface and the air bubble formation of the PVA film as in the optical micrograph in figure. The average size of air bubble of PVA film and STRF reinforced PVA films are about are 1.9E-8mm^2 and 7.06E-8mm^2.

Figure 5. Optical Micrograph of pure PVA and SCRF reinforced PVA Films

FTIR Analysis of Waste Scraped Rubber Fiber (SCRF) Reinforced PVA Films

The Fourier Transform Infrared Spectroscopy (FTIR) analysis of pure PVA films indicated the chemical functional group of PVA film as in the Figure 6 and Table 1. The FTIR transmittance spectra of the 5 w/v%, 10 w/v%, 15 w/v% and 20 w/v%, scraped tire rubber reinforced PVA film are shown in the Figure 7 and the chemical functional group of scraped tire rubber reinforced PVA films is as in the Table 2. The peak number 4,5,6 and 7 and 8 of the FTIR transmittance spectra of the 5 w/v% scraped tire rubber reinforced PVA film in the Figure 7 correspond to the waste scraped tire rubber fiber and other peak numbers are represented PVA. The resultant FTIR transmittance spectra were matched with chemical functional group of PVA and the scraped tire rubber fiber.

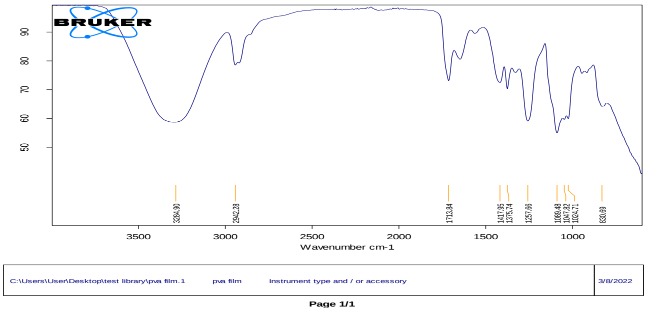

Figure 6. FTIR transmittance spectra of pure PVA film

Table 1 Chemical functional groups of FTIR spectra of pure PVA film.

Peak Number	Wave Number (cm^{-1})	Functional Group
1	3284.90	O-H stretching
2	2942.28	C-H stretching
3	1713.84	C=O stretching
4	1417.95	CH_3-O bending
5	1375.74	C-H bending
6	1257.66	C-O stretching
7	1089.48	C=O-C stretching
8	1047.82	C-O stretching
9	1024.71	C-O stretching

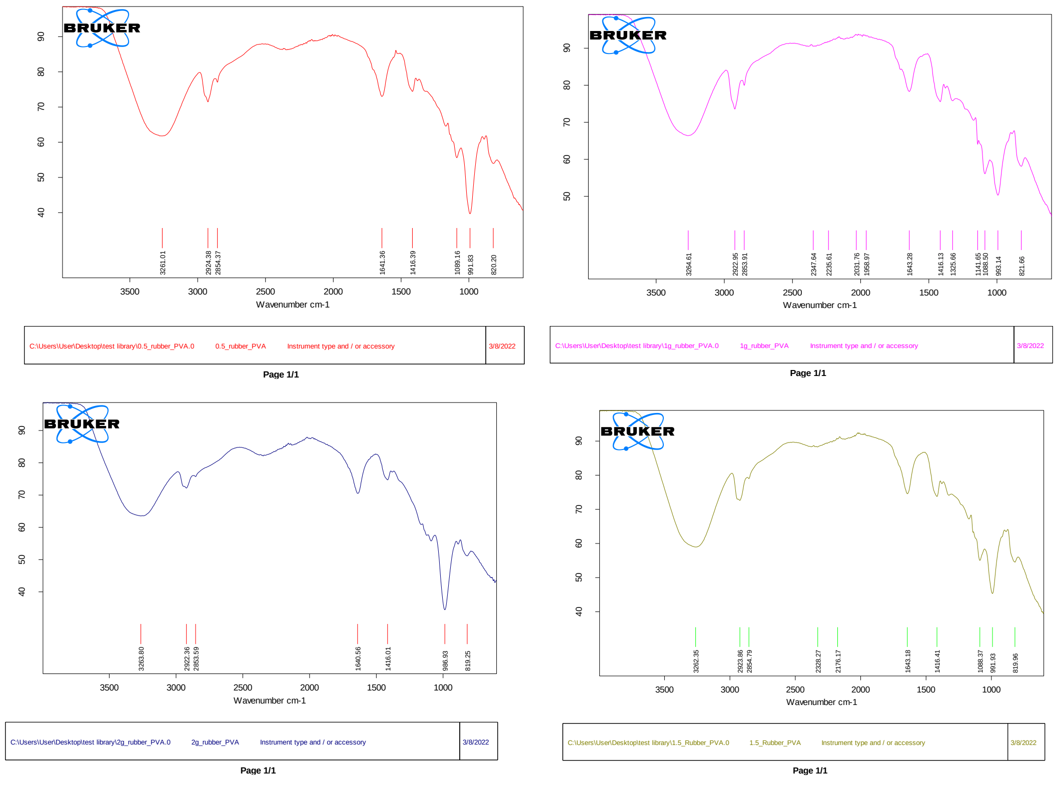

Figure 7. FTIR transmittance spectra of 5 w/v%, 10 w/v%, 15 w/v%, 20 w/v%, scraped tire rubber reinforced PVA films

Table 2 Chemical functional groups of FTIR spectra of 5w/v%, 10 w/v%, 15 w/v%, 20 w/v% scraped tire rubber fiber (STRF) reinforced PVA films

Peak Number	Wave Number (cm^{-1})	Functional Group
1	3261.01	O-H stretching
2	2924.38	C-H stretching
3	2854.37	C-H stretching
4	1641.36	[-C=C] bending
5	1416.39	[=CH_2] bending
6	1089.16	SiO_2
7	1377.66	[-CH_3] bending
8	991.83	P-O-C stretching
9	821.66	C=C-H stretching

Sound-Absorbing behavior of waste scraped rubber fiber (SCRF) reinforced PVA films

The oscilloscopic analysis of the acoustic absorption coefficient of pure PVA film and waste scraped tire rubber fiber (STRF) reinforced PVA films were shown in the Table-3,4,5,6 and 7. The frequency dependency of the acoustic absorption coefficient of the PVA film and the waste scraped tire rubber fiber (STRF) reinforced PVA films were depicted as in the Figure 8.

Table 3 Acoustic absorption coefficients of pure PVA film in the range of audio frequency 200 Hz to 2 kHz

Frequency	I_0 (V)	I (V)	α
200Hz	1.7	0.38	0.78
300Hz	1.6	0.4	0.75
400Hz	1.3	0.4	0.7
500Hz	1.5	0.52	0.65
600Hz	1.8	1.1	0.39
700Hz	2	1.4	0.3
800Hz	2	1.1	0.45
900Hz	1.75	0.6	0.65
1kHz	1.2	0.25	0.79
1.5kHz	0.36	0.032	0.91
2kHz	0.35	0	1

Table 4 Acoustic absorption coefficients of 5 w/v% SCRF reinforced PVA Film in the range of audio frequency 200 Hz to 2 kHz

Frequency	I_0 (V)	I (V)	α
200Hz	0.68	0.034	0.95
300Hz	0.6	0.044	0.94
400Hz	1.5	0.088	0.94
500Hz	2.4	0.1	0.95
600Hz	2.4	0.1	0.95
700Hz	2.4	0.07	0.97
800Hz	2	0.036	0.98
900Hz	1.4	0.024	0.98
1kHz	1	0.014	0.98
1.5kHz	0.32	0.003	0.90
2kHz	0.22	0.002	0.90

Table 5 Acoustic absorption coefficients of 10 w/v% SCRF reinforced PVA Film in the range of audio frequency 200 Hz to 2kHz

Frequency	I_0 (V)	I (V)	α
200Hz	0.48	0.017	0.96
300Hz	1	0.04	0.96
400Hz	1.4	0.084	0.94
500Hz	1.75	0.068	0.96
600Hz	2.6	0.056	0.97
700Hz	3.2	0.050	0.98
800Hz	2.3	0.028	0.98
900Hz	1.6	0.018	0.98
1kHz	1.2	0.09	0.92
1.5kHz	0.36	0.002	0.99
2kHz	0.24	0	1

Table 6 Acoustic absorption coefficients of 15 w/v% SCRF reinforced PVA Film in the range of audio frequency 200 Hz to 2kHz

Frequency	I_0 (V)	I (V)	α
200Hz	0.72	0.014	0.98
300Hz	0.96	0.04	0.95
400Hz	1.25	0.035	0.97
500Hz	1.6	0.049	0.96
600Hz	2.4	0.064	0.97
700Hz	2.3	0.062	0.97
800Hz	2.1	0.046	0.97
900Hz	1.5	0.026	0.98
1kHz	1.15	0.012	0.98
1.5kHz	0.36	0.002	0.99
2kHz	0.24	0	1

Table 7 Acoustic absorption coefficients of 20 w/v% SCRF reinforced PVA Film in the range of audio frequency 200 Hz to 2kHz

Frequency	I_0 (V)	I (mV)	α
200Hz	0.3	2	0.99
300Hz	0.9	22	0.97
400Hz	1	40	0.96
500Hz	1.55	12	0.99
600Hz	3	19	0.99
700Hz	3	28	0.99
800Hz	2	14	0.99
900Hz	1.6	9	0.99
1kHz	1.1	7	0.99
1.5kHz	0.34	6	0.98
2kHz	0.26	5	0.98

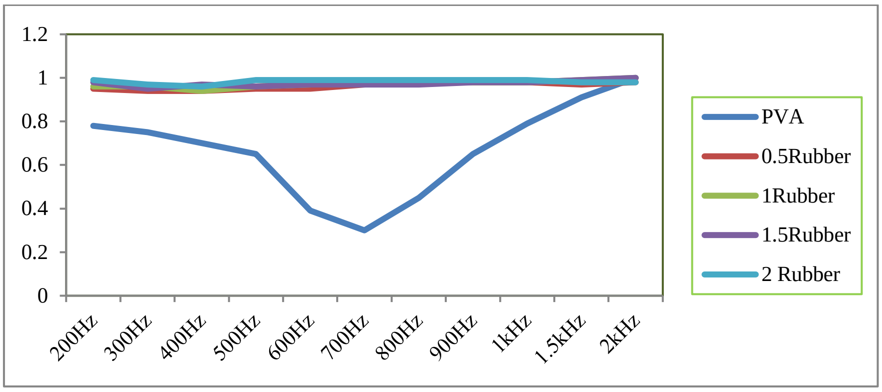

Figure 8 Acoustic Absorption Coefficient of pure PVA film and the waste scraped tire rubber fiber (STRF) reinforced PVA films as the function of the audio frequency in the range of audio frequency 200 Hz to 2 kHz

Conclusion

The waste scraped tire rubber fiber (STRF) reinforced PVA films have greater Acoustic absorption coefficient than the pure PVA film. The acoustic absorption coefficient of pure PVA layer is varied as the function of the acoustic frequency. The pure PVA layer has maximum acoustic absorption coefficient at the acoustic frequency 2 kHz and has minimum acoustic absorption coefficient at 700 Hz. All of the PVA acoustic absorber have large acoustic absorption coefficient at high frequency, 2 kHz due to their resonant frequency nature. This research has shown that the waste scraped tire rubber fiber (STRF) reinforced PVA films can be used as the Acoustic absorber to reduce sound pollution of the environment and may be one of the solutions for the waste car tire rubber recycling.

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