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Graphene oxide–polymer hydrogel: wettability and sound absorption

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Abstract

In this paper, we introduce a nanocomposite as a humidity-sensitive sound absorber. The nanocomposites were prepared using hydrogel polymer (HP) as a matrix and graphene oxide (GO) as a filler. Results show that the surface energy of the nanocomposite is 58.4 mJm^{-2} , and GO sheets increase the nanocomposite porosity from $2.6716 \text{ cm}^2 \text{ g}^{-1}$ (for HP) up to $3.246 \text{ cm}^2 \text{ g}^{-1}$. In addition, the diameter of nanocomposite pores is 8.5202 nm lower than that of HP (10.274 nm). To study the effect of humidity on the sound absorption, we exposed them to moisture for 30 and 60 min and then measured sound absorption. Results show an absorption peak for the HP at 1022 Hz with an attenuation value of 30%, while nanocomposite shows two main peaks around 1898 and 3300 Hz. In addition, results show that sound absorption peaks shift to higher frequency according to humidification time.

Keywords: Sound absorption, Graphene oxide, Moisture absorption, Nanocomposite.

1. Introduction

Sound absorbers have attracted remarkable attention in recent years due to their promising application in industry and life ¹⁻³. Sound-based devices can be divided into two categories with amorphous and crystal structures ^{4,5} ENREF 3. Phonon crystals have been widely studied to fabricate sound-based devices ⁶. For instance, Xue-Feng *et al.* designed and simulated acoustic crystals to transfer the sound in one direction. Such a system is made from square steel blocks and can control the frequency of transmitted sound by mechanical rotation of the blocks ⁷. In addition, by creating defects in a two-dimensional cylindrical grid immersed in water, one can conduct the sound waves and control their frequency ⁸. In addition, topological acoustic insulators are interesting due to their applications as sound absorbers ^{9,10}.

Among various sound absorber materials, nanocomposites are promising for sound-based devices ¹¹. Typically, porous materials are applied as a sound absorber, and many studies have been performed to understand the absorption mechanism of these materials ¹². The propagation of sound is affected by environmental conditions, and sound absorption is dependent on ambient humidity and temperature ^{13,14}.

The low-cost and biocompatibility of hydrogel polymers introduce them as a promising candidate for sound absorbing in the transportation and construction industries ¹⁵. Hydrogels are hydrophilic polymer with cross-linking and swollen ability, which retains large amounts of water. The moisture absorption of hydrogels by hydrophilic functional groups and their dissolution resistance is desirable to fabricate efficient sound absorbers ¹⁶. The swelling behavior has a significant effect on the physical and mechanical properties of the final hydrogel, and environmental humidity and temperature affect the hydrogel-based sound absorber. Adding GO to the HP can improve its mechanical, thermal, hydrophilicity and swelling properties. In addition, the properties of HP can be improved by varying concentrations of cross-linking agents in nano-composites ^{11,12}. Surrounding the reinforcing phase by hydrogel can improve sound absorption and increase the dissipation coefficient ^{6,11}. The size of the pores in a sound absorber determines the frequency of sound absorption ¹⁷⁻¹⁹. Controlling the sound in resonant cavities, acoustic diodes, thermoelectric is the subject of recent researches ^{20,21}, and sound waves can be controlled by phonon crystals ²⁰. To achieve an impedance-tunable sound absorber, one should make it sensitive to the external actuator. Synthesizing low-cost and efficient tunable sound absorbers is a challenge in acoustic

science^{22,23}. As reported reinforcing phases such as GO can be used as a reinforcing phase of composite to fabricate an efficient sound absorber¹¹.

In this paper, we used HP as a base polymer to fabricate humidity-sensitive sound absorber coating. GO was used to modify its surface energy and sound absorption, and the sound absorption of the prepared samples was measured after exposure to moisture at different times. In addition, the frequency of absorption peak shifts from 1022 Hz to 2000 and 3538 Hz after humidification. However, the absorption peak frequency for HGO is 1898 Hz, which increases by humidification for 30 and 60 min, respectively. This paper is organized as follows: in the materials and method section, we present the composite preparation and characterization methods. In the results and discussion section, we discuss the prepared sample composition and porosity. Finally, we present sound absorption results and discuss the effect of humidity on sound absorption of the prepared samples.

2. Materials and methods

3.1 GO synthesis:

GO were synthesized using the improved hummers method as reported previously by us^{11,24}. In a typical method, we dissolved 0.1 g of graphite with 15 ml of sulfuric acid (98%) and then stirred for 15 min at 25° C. Afterward, we added 0.3 g of KMnO₄ to the solution and placed it in a water/ice bath for 5 min. Afterward, KMnO₄ was removed by H₂O₂ at 40°C, and then graphite oxide was exfoliated by ultra-sonication. Finally, the solution was placed in a centrifuge with a speed of 1200 RPM to separate GO from graphite oxide¹¹.

3.2 Composite Synthesis: First, we milled the 500g of potassium polyacrylate (from Atieh Energy Company) for 60 min to obtain a powder. The resulting powder dissolved in 100 ml of deionized water and then stirred for 30 min at 35° C. Afterward, we added 5 ml of hydrochloric acid (37%) with 100 ml of deionized water to the resulting mixture. Finally, we dried the resulting solution in an oven at 70 ° C for 12 hours. To dope the GO in HP, we added 20 ml of GO to the primary solution and dispersed it for 30 min by sonication. The prepared polymers for measuring the sound absorption were made using a laser cutting machine of 3 cm in diameter and 1 cm in thickness. The sound absorption measurement conditions were performed according to Table 1.

3.3 Characterization

FTIR spectroscopy was performed by Thermo scientific model Nicolet iS10. Field emission scanning electron microscopy (FESEM) and X-ray diffraction spectroscopy (EDX) was done by MIRA3 from TSCAN Company. Brunauer Emmett Teller's (BET) experiment was performed using a Belsorp mini II from Microtrac Bel Corp. The weight of HGO for BET analysis was 0.0586 and 0.0547 gr. Impedance Tube was utilized from Manufacturer of BSWA Technology Company Model: BSWA, SW477+SW422.

3. Results and discussions

3.1 Composite characterization

FTIR is a powerful method to determine functional groups of the prepared nanocomposite ENREF 24. Figure 1 shows the FTIR spectra for GO, HP, and an HGO. In a typical FTIR spectrum for GO, the peaks at 3405, 1622, and 1732 cm^{-1} are attributed to O-H, C=O, and C=C stretching modes. In addition, the peak observed at 1053, and 1395 cm^{-1} are attributed to the C-O stretching and bending modes. The peak at 2923 cm^{-1} is related to the C-H, and two peaks at 1799 and 2315 cm^{-1} are attributed to C=O and C-O, respectively. As shown, the peak intensity of the O-H functional group increases for HP due to the presence of GO in the HGO. In addition, there is an extra peak in the HGO spectrum at 1622 cm^{-1} , corresponding to the C=C bond in GO. As shown, there is no considerable change in the spectrum after reinforcing the polymer by GO. The morphology of the prepared samples was investigated by FESEM. Figure 2 shows the porous surface of the prepared composite. As shown, the porosity of the HGO seems more than the HP, which will be discussed later.

To perform elemental analysis of the samples, we used the EDX experiment. The results of EDX are shown in Figure 3 and Table 2. As shown in Figure 3(a), about 49.04% of HP is carbon with 15.55% oxygen. However, according to Figure 3(b) and Table 2 for the HGO, 65.98% of the composite is carbon, and 18.75% is oxygen. Results show that carbon and oxygen in HGO are more than HP due to GO, which agrees with FTIR results.

Another factor in sound absorption is the porosity of sound absorbers ¹². Polymer porosity was investigated using BET analysis, and results show 3.2416 m^2g^{-1} and 2.6716 m^2g^{-1} specific surface areas for HGO and HP, respectively. In addition, the average diameter of the pores in the HP is 10.274 nm, while this is 8.5202 nm for HGO. The BET experiment was performed by the adsorption and desorption of nitrogen isomers at 77 K. According to BET theory; the gas adoption

can be done in multi-layered form, without any reaction with adjacent molecules²⁵. As shown in Figure 4, the absorption and desorption graph of the HP shows type III isotherm indicating weak interaction in the first layer between absorbent and absorber²⁵. However, as presented in Table 3, the HGO shows more porosity than the HP.

The contact angle of water droplets was measured on the surface of the HP and HGO. We recorded the contact angle of the water droplet as-dropped and after 120 seconds. The contact angle of the water droplets on the HP and HGO surface are 52.4° and 40.9°, respectively. Using the Neumann method, we obtained the surface energy by the following formula:

$$\ln\left[\gamma_l \left(\frac{(\cos \theta + 1)}{2}\right)^2\right] = \ln(\gamma_l) - \beta(\gamma_s - \gamma_l)^2 \quad (1)$$

In Eq. 2, γ_l , γ_s , and θ represent the surface tension of the liquid, sample, and the contact angle of a droplet, respectively. To obtain the surface energy, we measured the contact angle of various liquids (including ethylene glycol, water, acetone, DMF, and H₂O₂) on the surface. By plotting $\ln\left[\gamma_l \left(\frac{(\cos \theta + 1)}{2}\right)^2\right]$ versus γ_l and fitting a second-order curve (Figure 5), β is determined as $-0.0001 \text{ m}^4(\text{mJ})^{-2}$, and surface energy of HP and HGO is calculated as 51.5 and 58.4 mJ/m^{-2} , respectively. Results confirm that the hydrophilicity of the HP increases due to GO in the polymer²⁶.

3.2 Sound absorption

To measure the sound absorption, we used a two-microphone impedance tube with a diameter of 3 cm (BSWA model 422). The absorption coefficient, reflection, impedance, and sound admittance were measured by the impedance tube. Sound reflection measurement was carried out using the transfer function method, according to Eq. 2:

$$r = r_r + ir_i = H_{12} + \frac{H_l}{H_R} - H_{12}e^{i2kx_1} \quad (2)$$

where r_r and r_i are the real and imaginary components of the reflected wave, respectively. x_1 is the sample distance from the farther microphone. H_l and H_R are also the transfer function for the incident and reflected wave, and H_{12} is the transfer function between the two microphones. Finally, the absorption of sound was obtained from²⁷:

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \quad (3)$$

To study the humidity effect on the sound absorption of the prepared samples, we exposed them to the humidity (100% RH) for 30 and 60 min. As shown in Figure 6(a), the main absorption peak appears at 1898 Hz with an absorption coefficient of 0.65, while the second absorption peak is seen at a frequency of 3300 Hz with an absorption value of 0.25. However, for the HP, we see an absorption peak at 1022 Hz with a value of 0.3. The difference in the frequency of the absorption peak between HP and HGO can be attributed to the pores' diameter²⁸. By exposing the HGO to the humidity for 30 min, the peak shifts to the frequency of 2822 Hz with an absorption coefficient of 0.87 (Figure 6(b)). However, for HP samples, the absorption peak appears at 2000 and 4906 Hz with absorption value of 0.88 and 0.62, respectively. In addition, HGO and HP after 60 min humidity exposure show the peak at 3884 and 3538 Hz, respectively (Figure 6(c)). As a result, the frequency difference between HGO and bare HP decreases from 822 to 346 Hz by increasing the humidification time to 60 min.

Results in Figure 6 show an increase in sound absorption due to humidity. Sound absorbents can reduce sound energy by converting vibrating energy into heat^{29,30}. As shown in Figure 6, sound absorption in HGO is greater than HP, and the moisture increases the intensity of sound absorption peak for HGO with the value of 0.87 and 0.84.

According to the Helmholtz theorem, in a resonance condition, the impedance becomes zero³¹. Figure 7(a) shows acoustic impedance for the HGO, which is zero in the range of 1500 to 2000 Hz and 3000 to 3500 Hz. According to the Helmholtz plot, when the acoustic impedance is zero, resonance occurs in the system¹¹. Figure 7(a) shows the maximum domain of impedance in the frequency range of 2000 to 3000 Hz for HP and HGO, indicating the coating's resistance to sound waves. As shown in Figure 7(b), the acoustic impedance for HGO has the highest amplitude at the frequency range of 2500 to 3000 Hz. Figure 7(c) also shows that the acoustic impedance at 2500 to 4500 Hz for HGO has the highest amplitude. Acoustic impedance is the ratio of applied sound pressure to the speed of the matching particle¹¹. Therefore, at such a frequency of sound, one see maximum sound absorption of the prepared samples.

4. Conclusions

In summary, sound absorbers were prepared based on HP and GO, and then sound absorption was measured. We show that GO increases the surface energy of the nanocomposite as well as sound absorption. FESEM and BET results show a porous structure for HP while doping it by GO as

reinforcing phase increases porosity. The sound absorption was studied using an impedance tube in the frequency range of 1000 to 6000 Hz. Results show that the HGO shows two main peaks around 1898 and 3300 Hz, while HP exhibits one peak at 1022 Hz. In addition, moisture exposure tunes the sound absorption, and two absorption peaks shift to 2000 and 4906 Hz.

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All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Table 1: Environmental conditions for measuring sound absorption.

Atmospheric pressure (Pa)	88310
Temperature (° C)	27
Humidity (%)	38
Sound speed (m / s)	347
Air density (kg / m ²)	1

Table 2: Quantitative results obtained from the EDX spectrum of HP and HGO.

Element	Shell	Weight%		Atomic%	
		HP	HGO	HP	HGO
C	K	27.12	47.08	49.04	65.98
O	K	11.46	17.82	15.55	18.75
Si	K	4.95	0.73	3.83	0.44
Cl	K	4.01	0.78	2.45	0.37
K	K	52.46	33.60	29.13	14.46

Table 3: BET and BJH analysis details for HP and HGO.

Sample	Analysis	Special surface area (cm ² /g)	Total volume of pore (cm ³ /g)	Mean pore diameter (nm)
HP	BET	2.6716	0.00686	10.27
	BJH	8.299	0.00823	1.29
HGO	BET	3.242	0.00690	8.52
	BJH	8.939	0.00945	1.29

Figure 1: FTIR spectrum of GO, HP, and HGO.

Figure 2: (a) FESEM image of HP, and (b) HGO at the scale of 200 nm.

Figure 3: EDX Spectrum of (a) HP, and (b) HGO.

Figure 4: (a) and (b) show BET, and (c) and (d) show BJH analysis of HP and HGO, respectively.

Figure 5: The fitted curve on contact angle results of various liquid to calculate the surface energy of HP and HGO.

Figure 6: Sound absorption of (a) as-prepared, (b) after 30 min humidification and (c) after 60 min humidification.

Figure 7: Acoustic impedance of HGO and HP after humidification for (a) 0, (b) 30, and (c) 60 minutes.

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Figures

Figure 1

FTIR spectrum of GO, HP, and HGO.

Figure 2

(a) FESEM image of HP, and (b) HGO at the scale of 200 nm.

Figure 3

EDX Spectrum of (a) HP, and (b) HGO.

Figure 4

(a) and (b) show BET, and (c) and (d) show BJH analysis of HP and HGO, respectively.

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The fitted curve on contact angle results of various liquid to calculate the surface energy of HP and HGO.

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Acoustic impedance of HGO and HP after humidification for (a) 0, (b) 30, and (c) 60 minutes.