Journal of Polymers and the Environment (2024) 32:1860–1867
https://doi.org/10.1007/s10924-023-03106-3

ORIGINAL PAPER

Sound Absorption and Natural Polysaccharides: The case of Persian Gum and Tragacanth Gum

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Accepted: 19 October 2023 / Published online: 28 October 2023

Abstract

To prepare high-performance sound absorbing materials, the use of plant materials is a new approach based on environmental protection. In this study, two types of gum (Persian Gum and Tragacanth Gum) and Starch, gelatin and wheat straw were used as environmental friendly materials. The Three samples were prepared with certain weight-volume compositions of these materials based on the sol-gel and freeze-drying method. The manufactured samples were evaluated in terms of sound absorption properties, thermal stability and mechanical properties. The results showed different structures in terms of microspores and macrospores. the sample containing the combination of two gums (Persian Gum and Tragacanth Gum), with density (30.0358 g/cm), porosity (94.80%) and sound absorption coefficient (0.44) shows better performance than the other two samples. In this way, the sound absorption coefficient in high frequencies showed more than 70% improvement in such samples.

Keywords Persian Gum · Tragacanth Gum · Sound Absorption · Polysaccharide

Introduction

Noise pollution is undoubtedly one of the major problems in today's society. Therefore, a wide range of people, whether at work or home, are exposed to the risks of exposure to noise as a factor of physical harm [1–3], noise pollutions accounts for around 24% of the pollutant loads responsible for health risks. The adverse effects of sound on health include hearing impairment, concentration disorder, anxiety, tachycardia and hypertension [4, 5]. considering the wide variety of health impacts of noise; evaluation and control of noise have always been of interest to researchers. So, one of the control measures for noise sources is the use of sound absorbers. Sound-absorbing materials, due to their low cost, suitable molding properties and high porosity, perform well in sound absorption [6]. Sound waves collide with the absorbent material and due to friction with the walls and the air inside the pores, the sound energy is lost in the form of heat energy [7–10]. Aerogels, foams or polymers are materials which are widely used as sound absorbers. The polymer sponge is a composition in which gas bubbles are dispersed in the polymer matrix and form a two-phase gas-solid structure. In the gas phase, pores called cells are formed in the sponge. Therefore, if these pores (cells) are connected to each other, the sponge is called an open cell, otherwise, it is called a closed cell. The tensile strength and acoustic and thermal properties of polymer sponges change according to the cell type [11, 12]. Considering that most commercial foams, such as polyurethane foam, are obtained from fossil fuels and are non-biodegradable, absorbent materials that are made from degradable resources have received much attention. In 1931, S. Kistler introduced the term aerogel [13]. Aerogel is a dried gel in which the liquid part of the gel is replaced by air [14]. In general, aerogels are examples of materials with high volume, low density and high porosity, whose structure and pores can be changed by various methods at the nanoscale [15]. They are considered as a group of ideal materials for a wide range of applications

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such as thermal insulation, sound insulation, sensors and water and air pollutant absorbers [16–19]. Polysaccharide materials including agar, starch, cellulose, chitosan, pectin and alginate can be used to make aerogels. Recently, polysaccharide-based aerogels have attracted the attention of researchers due to many properties and characteristics such as biodegradability, abundance and high stability [20].

Among polysaccharides, Konjac glucomannan (KGM) has the ability to create a three-dimensional skeletal structure in aerogels due to its macromolecular chain structures [21–23]. As this internal plasticity leads to creation of a sound absorbing material with suitable performance [24]. Also, several studies have shown the effect of improving and increasing sound-absorption by using plant extracts in making aerogels [25–27]. Based on these findings, this material has been used in combination with other materials in other studies to improve sound absorption performance [20]. So, it appears that this field has a promising future. Persian Gum and Tragacanth Gum are anionic polysaccharides that are naturally derived from plant species. These materials are biodegradable, ecologically friendly, safe and stable and have high gelling properties [28–30].The present study aimed to investigate the sound absorption function, thermal stability and mechanical properties of a new composite aerogel based on native Iranian polysaccharides, including Persian Gum and Tragacanth Gum, with the addition of starch and wheat straw on a laboratory scale. The information collected from this study in relation Persian Gum and Tragacanth Gum will create new perspectives for the use of these two natural and renewable materials as aerogels.

Materials and Methods

Materials

Persian Gum (PG, pharmaceutical grade) (Mw 1180 KDa) and Tragacanth Gum (TG, pharmaceutical grade) (Mw 850 KDa), were purchased from Tehran Biochemical Technology Co., Ltd. (Iran). Other ingredients, such as potato starch and gelatin were purchased from Merck, Co (Darmstadt, Germany). Also, wheat straw was collected from an agricultural field in Ilam province, Iran. After washing, it was dried at 90 °C. Mesh 160 (pore size 94 µm) was used to homogenize the powder.

Preparation

Based on the process developed according to previous research, in this study, the sol-gel method and the freeze-drying method were used to prepare 3 samples of aerogels [20, 31]. The composition of the first sample included TG (2.00%, w/v), PG (2.00%, w/v), S (2.00%, w/v), G (1.00%, w/v) and WS (0.5%, w /v), the composition of the second sample included TG (4.00%, w/v), S (2.00%, w/v), G (1.00%, w/v) and WS (0.5%, w/v) and the composition of the third sample was consisted of PG (4.00%, w/v), S (2.00%, w/v), G (1.00%, w/v) and WS (0.5%, w/v). The schematic process of preparing aerogels is shown in Fig. 1. Firstly, TG (2.00–4.00%, w/v) and Persian gum (2.00–4.00%, w/v) were soaked in 20 ml of double distilled water for 24 h. Also, gelatin (0.5%, w/v) was dissolved in a beaker with 20 ml of double-distilled water and placed in a 60-degree water bath for half an hour. Straw and starch were placed in 40 ml of water in a beaker at a temperature of 90 degrees and were mixed with a mixer at 600 rpm. Next, gelatin, TG and PG were added to the straw and starch mixture and were stirred for one hour to create a homogeneous mixture. Then the resulting mixture was poured into a six-well cell culture plate and immediately was placed in a

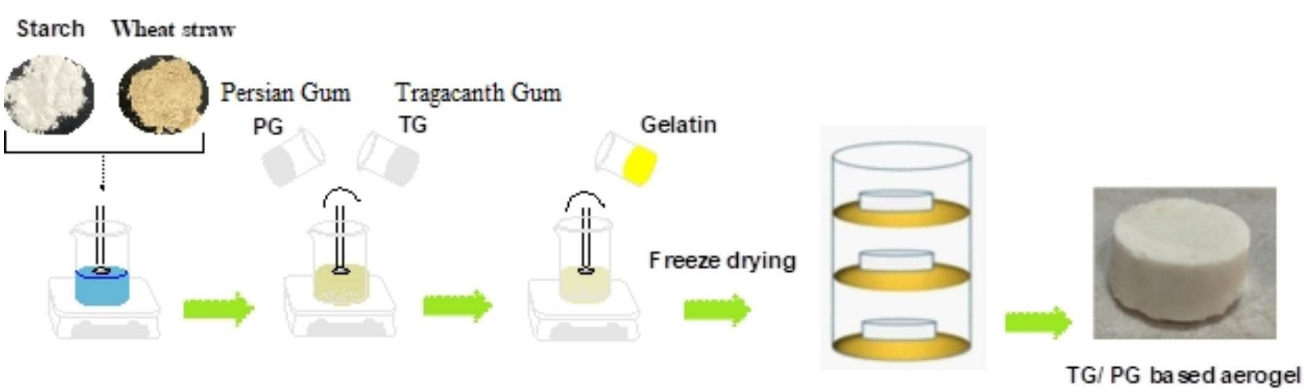

Fig. 1 The schematic process of preparing aerogels

refrigerator at 4 degrees Celsius for two hours for the aging process. After this stage, the product was transferred to a freezer (O-DUFD-558, Operon, Korea) with a temperature of -35 degrees Celsius for 10 h. In the last step, the product was transferred to the freeze dryer (Alpha 1–4 LSC basic, CHIRIST, Germany) with a temperature of -55 and a vacuum of one Pascal for 24 h. In order to facilitate the description of aerogels, the samples are shown as TG0PG0S0G0WS0, where TG, PG, S, G, WS represent TG, starch, gelatin and wheat straw, respectively. Also, the numbers after the above items indicate the percentage by weight and volume.

Characterization of Aerogels; Determination of Microstructures and Pores

A scanning electron microscope (SEM) (1455VP, LEO, England) with an accelerating voltage of 21 kV equipped with X-ray spectrophotometer was used to determine the microstructures and pore size. For this purpose, biomass aerogel samples with dimensions of 2 mm x 2 mm x 1 mm were cut using a sharp razor and were covered with a thin layer of gold using a spatter.

Determination of Density

To measure the density, the dimensions of the aerogel were cut to $10 \times 20 \times 10$ mm using a Vernier caliper. Then the weight of each sample was determined with a sensitive laboratory scale (KERN ABJ 220-4NM, Germany) and the density of the aerogel was calculated using this formula (1). The steps were repeated three times for each sample and the average density was recorded.

$$\rho = m/V \quad (1)$$

where ρ is the density g/cm3, m is the weight of the aerogel and v is the volume of the aerogel.

Determination of Porosity

To determine the porosity, biomass aerogels were first weighed. Then each sample was placed in a container containing ethanol. The container containing ethanol and aerogel was placed in a vacuum desiccator until no more air bubbles came out of the aerogel. Next, the aerogel was removed from the container and the container was reweighed with the remaining ethanol. According to Eq. (2) below, the amount of porosity was calculated.

$$Porosity(\div) = (m_1 - m_2 - m)/(m_1 - m_2) \times 100\div \quad (2)$$

where m is the initial weight of the aerogel, m1 is the weight of the aerogel and ethanol absorbed by the sample, and m2 is the weight of the remaining ethanol in the container.

Sound Absorption Coefficient

In general, there are different methods for measuring the absorption coefficient of sound absorbing materials. In the present study, the sound absorption coefficient of aerogels was measured using an impedance tube laboratory set-up (BSWA, model 477, China). The manufactured aerogel samples were cut according to two diameters; 100 mm diameter for frequencies 80-1600 Hz and 30 mm diameter for frequencies 1600–6300 Hz. All measurements were done 3 times for each sample.

Determination of Mechanical Properties

The mechanical properties of the manufactured aerogels were evaluated using a texture analyzer (TPA, Koopa, Iran) equipped with a five-kilogram load-cell and a measurement accuracy of 0.01.

Thermal Analysis

In order to check the thermal stability of the manufactured aerogels, the thermal analysis (TA) of the developed aerogels was performed by a TA instrument (SDT- Q600, USA). First, the samples were powdered. Then, the samples were subjected to a flow of Argon gas with a flow of 20 ml per minute which were heated from 20 to 600 degrees Celsius at a rate of 20 degrees per minute, and thus the weight change curves showing the thermal stability of the samples were drawn.

Statistical Analysis

IBM SPSS software V.20 was used for descriptive statistics and comparison of means at the significance level of 0.05.

Results and Discussion

Figure 2 shows the macro and microscopic images of these 3 samples. Also, SEM microscopic images in two magnifications of each sample are shown in Fig. 2. The microscopic structure of composite aerogel sample 1 (Fig. 2, c) showed a honeycomb structure with a large number of pores and a uniform pore wall. In the SEM images of aerogel sample 2 (Fig. 2e, f), the pores created are spherical with a small number, which indicates the low porosity in the sample. Also, the microscopic images of aerogel sample 3 (Fig. 2h,i) showed

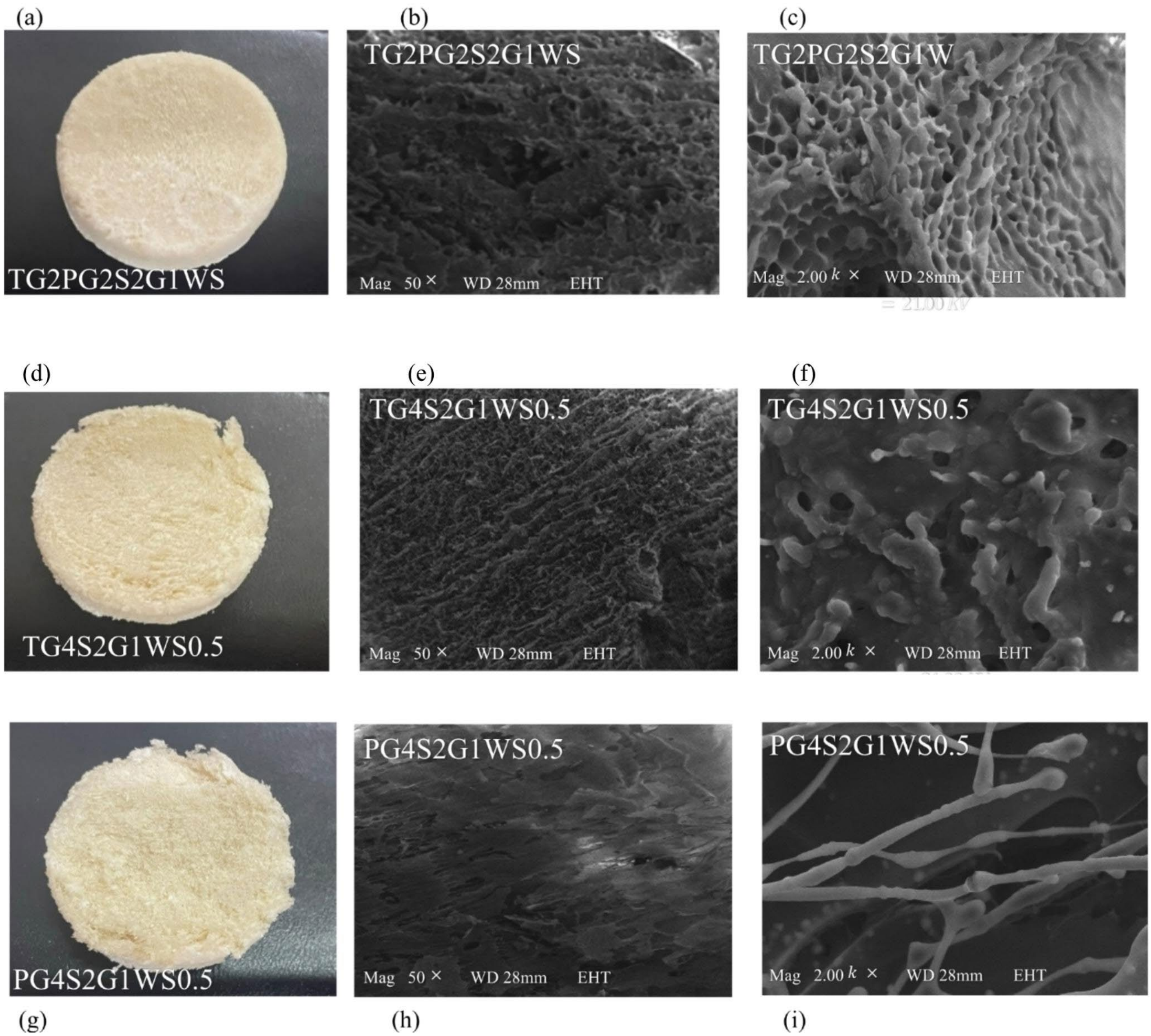

Fig. 2 Photo and SEM images with two magnifications (×50 and ×500) for PG and TG (a-c); PG (d-f) and TG (g-i) aerogel

Table 1 the results of the comparison between the Density and porosity of aerogels

Code	1	2	3	
Sample	TG2PG2S2G1WS0.5	TG4S2G1WS0.5	PG4S2G1WS0.5	P-value*
Variable				
Porosity (%)	94.800 ± 0.04	90.113 ± 0.07	87.825 ± 0.02	0.042
Density(g/cm3)	0.0358 ± 0.0006	0.0460 ± 0.0009	0.0467 ± 0.0013	0.05

*Significate level < 0.05

the layered structure. Therefore, the amount of pores created in this sample was much lower than the other two samples. As a result, the absorption performance of produced aerogels was affected by the number of pores and its distribution in the microscopic structure of the aerogel. Also, by examining the images, it can be seen that the samples were heterogeneous due to the wide range of pore sizes. Similar finding were also reported by Wang et al., Do et al., and Wie et al., [20, 32, 33]. This means that the size of the particles was in the range of 5 to 100 µm.

Table 1 presents the comparison of the density and porosity analysis results between the 3 prepared aerogel samples. The density and porosity analysis for sample 1 was 0.358 g/cm3 and 94.8%, respectively; which showed a statistically significant difference with other sample results ($p < 0.05$). Also, as similar finding, in the study of Wang et

Table 2 Sound absorption coefficients of samples with different loading of PG and TG

Frequency Hz Sample code and name			125	250	500	1 k	2 k	4 k	6.3k	Weight gr
1	TG2PG2S2G1WS0.5	Mean	0.048	0.098	0.321	0.562	0.632	0.687	0.796	0.6040
		SD	0.007	0.018	0.022	0.021	0.012	0.01	0.026	0.0233
2	TG4S2G1WS0.5	Mean	0.038	0.065	0.238	0.342	0.482	0.521	0.574	0.7905
		SD	0.008	0.010	0.103	0.071	0.124	0.037	0.080	0.0048
3	PG4S2G1WS0.5	Mean	0.021	0.019	0.098	0.298	0.352	0.448	0.441	0.8138
		SD	0.002	0.006	0.015	0.038	0.013	0.077	0.045	0.0066

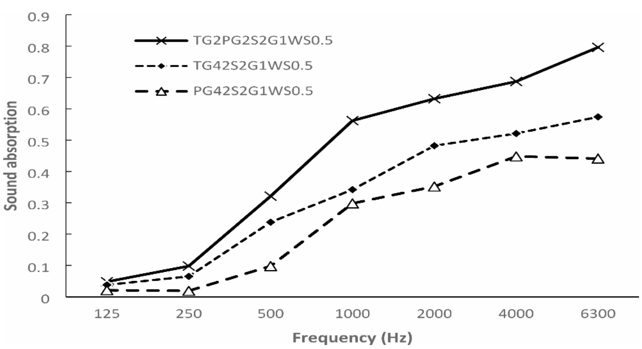

Fig. 3 Sound absorption efficiency of aerogels (TG2PG2S2G1WS0.5, TG4S2G1WS0.5, PG4S2G1WS0.5

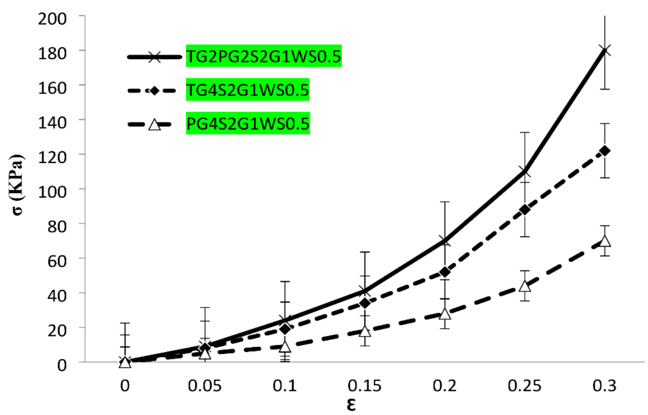

Fig. 4 The compressive strain–stress curves for aerogels prepared from the different constitution

al., the change in the weight and volume percentage of the consumed polysaccharide showed a positive effect on the performance of the aerogel made [20].Table 2 presents the means of sound absorption coefficient values measured in three samples with different amounts of PG and TG.

Figure 3 shows the results of sound absorption performance in each of the three aerogel samples made in the frequency range of 125 Hz-6.3 kHz. According to the graphs drawn for all three samples, the trend of absorption coefficient was increasing. The highest absorption coefficient of sample 1 (TG2PG2S2G1WS0.5) was equal to 0.8 at the frequency of 6300 Hz. According to the results, the sound absorption performance of sample 1 in all frequencies (125 Hz-6.3 kHz) was better than the other two samples. Also, the same conditions can be seen in sample 2 (TG4S2G1WS0.5) compared to sample 3 (PG4S2G1WS0.5). The sound absorption coefficient was strongly influenced by the morphology of the aerogel, including the density (related to the cell wall thickness) and the characteristics of the pores (size, number, internal communication and bending). In a study by Thai al., and Simón-Herrero et al., some supporting findings are reported [34, 35]. Lu et al., investigated the sound absorption efficiency of prepared lignocellulose aerogel. The results showed that sound absorption at frequencies of 1 and 2 kHz was 0.877 and 0.78.2, respectively [36]. In another study Du Tran et al., stated the high sound absorption performance ($\alpha = 0.6$) of rice straw aerogels [27]. The results of the present study also showed a higher sound absorption coefficient in the frequencies of 1-6.3 kHz. In other words, the increase in the sound absorption coefficient in this frequency range can be due to the small size of the pores of the cells and the increase in the air flow resistance, which leads to more friction of the sound waves with the walls and air molecules inside the pores, which is consistent with the results of the study by Choe et al., [37].

The results of examining the changes in the structural performance of the manufactured aerogels against pressure are presented in Fig. 4. Three types of aerogel made with different compounds were tested in order to investigate the compressive behavior. Each aerogel sample was examined three times and average was chosen to draw the curve (Fig. 4). The linear elasticity, plateau and condensation phases represent the nonlinear stress-strain relationship. In the meantime, the first phase is more specific. In the present study, the volume ratio of gelatin and wheat straw was constant in all 3 aerogel samples. The strength of aerogels was affected by the polysaccharide composition used. As shown in Fig. 3, the three studied aerogels have different strengths, and the aerogel with a combination of TG and PG (TG2PG2S2G1WS0.5) showed the best compressive strength due to the thicker pore walls. Other studies in this field have supported these findings using different plant based materials [20, 22, 27, 38].

As the microscopic structure of the samples in the Fig. 2 shows, with the change in the composition of the gum used in aerogels, the strength of the structure from the state of interwoven holes to the state of lamellae shows a downward trend. In general, the strength of the samples has increased due to the addition of the type of gum in the matrix. In other words, the type and amount of gum used in the cell structure make the cell walls resistant to destruction, which ultimately leads to increased strength. Same results were obtained by other studies [20, 39, 40].

Also The relationship between the weight loss of the aerogels and temperature is shown in Fig. 5. The results showed that the thermal decomposition of aerogels has two phases. Due to the porous and hydrophilic structure of aerogels, there was some water in the samples, and due to the evaporation of this amount of water, the first stage of mass reduction occurred from about 30 to 100 degrees Celsius. The second stage of mass loss occurred at about 100 degrees Celsius, which was due to the breakdown of polysaccharides and the destruction of amino acids of proteins. As in Fig. 5a-c, it is shown that the percentage of degradation of the aerogel made from the combination of TG and Persian gum (TG2PG2S2G1WS0.5) was 87.15%, and this factor was 96.06% in the aerogel made with TG (TG4S2G1WS0.5), and in the aerogel with base Persian gum (PG4S2G1WS0.5) it was 96.15%. As a result, in the aerogel of sample 1, the amount of weight loss at the investigated temperature was lower than the other two samples. Rapid loss of mass occurred in all three samples above 250 °C (Fig. 5a.), and the aerogel made with TG and PG had the maximum resistance and its average heat stability was 279.24ºC.

Conclusion

In this study, new polysaccharide aerogels based on Tragacanth Gum and Persian gum were successfully made from completely natural, environmental friendly and low-cost materials using the freeze drying method. In all three samples, pore structure, sound absorption properties, mechanical and thermal properties were investigated. The results showed that compared to the other two samples, aerogel (TG2PG2S2G1WS0.5) with an NRC value of 0.44 had the highest sound absorption properties. Also, the investigation of thermal properties showed that in aerogel (TG2PG2S2G1WS0.5) the main decomposition temperature ranged from 279.24 to 371.94 degrees Celsius, which was higher than TG4S2G1WS0.5 and PG4S2G1WS0 aerogels. The (TG2PG2S2G1WS0.5) aerogel had the highest porosity (94.80 ± 0.04%) and the lowest density (0.035 g/cm^2), and the SEM images also showed that the combination of Tragacanth Gum and Persian gum had improved the condition of the pores, due to the fact that in this study, the amount of volume percentage of gelatin and straw was constant in all samples, and only in the gum part, changes in weight% and volume were applied, so, the performance of aerogels has been affected by this variable. When adding and changing the content of gum in aerogels, the size and uniformity of pore distribution of aerogels changed depending on the amount and composition of gum (Fig. 2). In such a way that the uniform distribution of the pores gradually decreased and the walls of the aerogel pores appeared as open pores

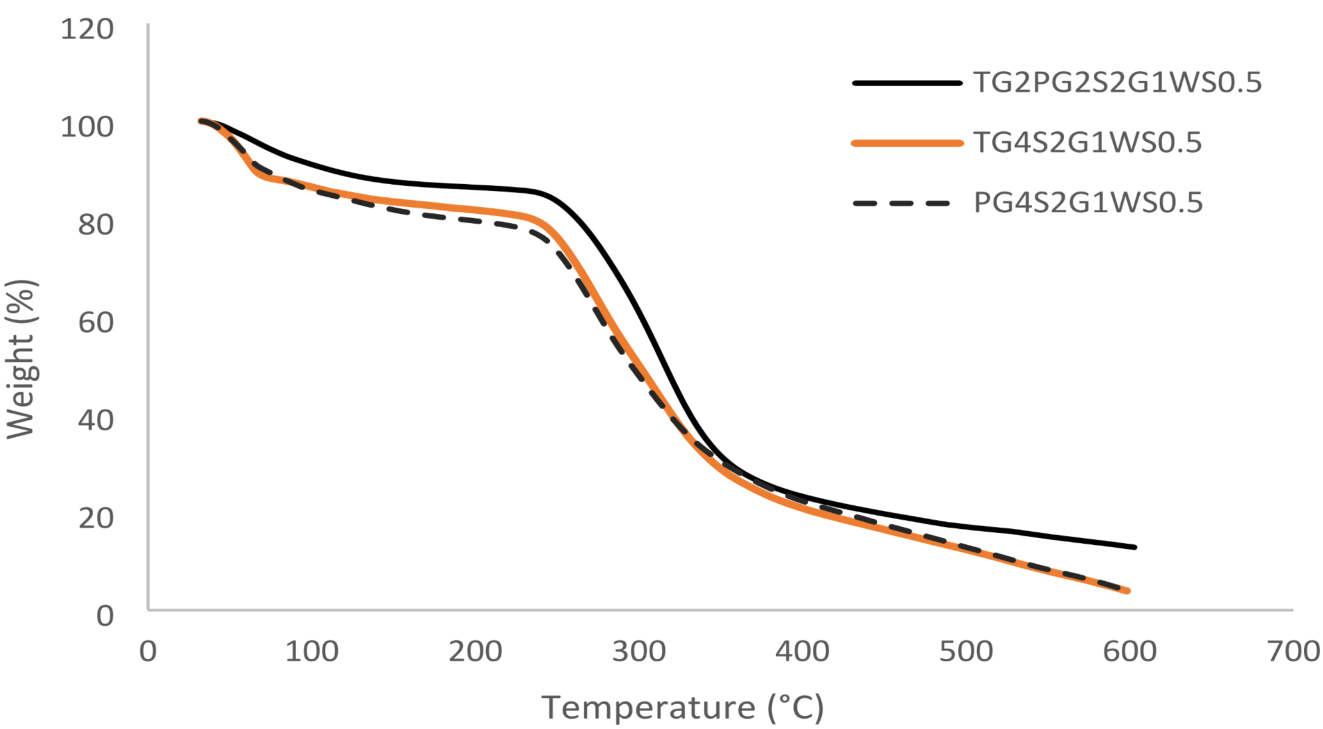

Fig. 5 The thermal gravimetric analysis (TGA) of TG2PG2S2G1WS0.5, TG4S2G1WS0.5 and PG4S2G1WS0.5 aerogels

due to the change in the composition of the pore structures of the aerogels.

The information collected from this study regarding TG and PG will create new perspectives for the use of these two natural and renewable materials as aerogels.

Acknowledgements This article was derived from a thesis by Mahsa Khormi as a part of an M.Sc degree in the field of occupational health engineering. The authors are thankful to the Office of Vice President for Research in Environmental Technologies Research Center Ahvaz Jundishapur University of Medical Sciences, which supported the project with registration number ETRC-0112.

Author Contributions H.R, A.S, M.K and B.F.D. design the study, M.K and B.F.D.wrote the main manuscript text and M.K prepared figures. All authors reviewed the manuscript.“

Declarations

Competing Interests The authors declare no competing interests.

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