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Enhancing sound transmission loss of polyurethane foams using waste soda glass filler

Atık soda cam dolgusu kullanılarak poliüretan köpüklerin ses iletim kaybının artırılması

Ayşenur YEŞİLYURT*

Bursa Teknik Üniiversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Kimya Mühendisliği Bölümü, 16310, Bursa

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Abstract

Sound transmission mechanisms and sound transmission losses are of great importance in providing acoustic comfort. Research has focused on developing materials and structures that will reduce sound transmission loss. The increasing amount of waste disrupts the ecological balance; this situation brings about global warming, air and soil pollution. These environmental effects negatively affect the lives of all living things, especially humans, and also harm the economy. Combating global pollution has become one of the primary goals of scientists. Recycling provides significant economic benefits as well as protecting both human health and natural resources. In this study, polyurethane foams used in the automotive industry and many other areas were produced by adding waste soda glass powder at various rates while keeping the isocyanate/polyol ratio constant. The durability of the produced foams was tested by apparent density measurement, wettability by contact angle analysis, organic bond structures by FT-IR spectroscopy and acoustic properties by sound transmission loss analysis. It was determined that soda glass powder did not react with the foams and that the produced foams exhibited hydrophobic properties. The acoustic properties of the filler foams were higher than the neat foam in almost the entire frequency range (65-6300 Hz). The sample coded PU-SG4 is the sample that exhibits the best acoustic properties by reaching 9.28 dB, 9.10 dB and 13.48 dB values in the low, medium and high frequency regions, respectively. In the high frequency range region, all of the soda glass added foam composites reached a sound transmission loss of over 13 dB.

Keywords: Polyurethane foam, Sound transmission loss, Waste soda glass

Öz

Ses iletim mekanizmaları ve ses iletim kayıpları, akustik konforun sağlanmasında büyük önem taşır. Araştırmalar, ses iletim kaybını azaltacak malzeme ve yapılar geliştirmeye odaklanmıştır. Artan atık miktarı ekolojik dengeyi bozar; bu durum küresel ısınmayı, hava ve toprak kirliliğini beraberinde getirir. Bu çevresel etkiler, başta insan olmak üzere tüm canlıların yaşamını olumsuz etkiler ve ekonomiye de zarar verir. Küresel kirlilikle mücadele, bilim insanlarının öncelikli hedeflerinden biri haline gelmiştir. Geri dönüşüm, hem insan sağlığını hem de doğal kaynakları korumanın yanı sıra ekonomik açıdan da önemli faydalar sağlar. Bu çalışmada, otomotiv endüstrisi ve diğer birçok alanda kullanılan poliüretan köpükler, izosiyanat/poliol oranı sabit tutularak çeşitli oranlarda atık soda camı tozu eklenerek üretilmiştir. Üretilen köpüklerin dayanıklılıkları görünür yoğunluk ölçümü, ıslanabilirlikleri temas açısı analizi, organik bağ yapıları FT-IR spektroskopisi ve akustik özellikleri ses iletim kaybı analizi ile test edilmiştir. Soda camı tozunun köpükler ile reaksiyona girmediği, üretilen köpüklerin hidrofobik özellik gösterdikleri tespit edilmiştir. Katkılı köpüklerin akustik özellikleri katkısız köpüğe göre neredeyse tüm frekans aralığında (65-6300 Hz) daha yüksek çıkmıştır. PU-SG4 kodlu numune, düşük, orta ve yüksek frekans bölgelerinde sırasıyla 9.28 dB, 9.10 dB ve 13.48 dB değerlerine ulaşarak en iyi akustik özellikleri sergileyen numunedir. Yüksek frekans aralığı bölgesinde soda cam katkılı köpük kompozitlerin tamamı 13 dB'nin üzerinde ses iletim kaybına ulaşmıştır.

Anahtarkelimeler:*Poliüretan köpük, Ses iletim kaybı, Atık soda camı*

*Ayşenur YEŞİLYURT;aysenur.erdogan@btu.edu.tr

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1. Introduction

Polyurethanes (PUs) are formed by the reaction of two main raw materials: isocyanate and polyols (Alsuhaibani et al., 2023; Das & Mahanwar, 2020; Pinto et al., 2024). Isocyanates, whose raw material is petroleum, are used as hardeners in polyurethane production. Isocyanates are liquid at room conditions and are highly reactive substances. Polyols, on the other hand, contain at least two or more functional –OH groups in their structures. The chain structure of the polyol, the number of hydroxyl groups and other groups it contains play a critical role in determining the properties of the final product. Urethane bonds (-NHCOO-) are formed by reacting with isocyanate groups through the functional groups of the polyol structures (Alsuhaibani et al., 2023; Batra, 2024; Das & Mahanwar, 2020; Wang et al., 2023).

Polyurethane foams are used in many sectors such as construction and automotive thanks to their positive properties such as excellent thermal insulation, low density, high specific strength, and good dimensional stability (Akindoyo et al., 2016; Ates et al., 2022; Jiang et al., 2023). Polyurethane foams are divided into two classes as rigid polyurethane and flexible polyurethane according to their strength (Salino & Catai, 2023; Tamaddoni Moghaddam et al., 2023). The flexibility and rigidity of the foam material depends on the raw materials and agents used in foam production, as well as the isocyanate and polyol ratio (Akindoyo et al., 2016; Das & Mahanwar, 2020; Wang et al., 2023). In the literature, studies have been conducted on foams produced with different NCO/OH ratios, foams prepared using different types of polyols, and organic and inorganic additives added to a fixed NCO/OH ratio (Coman et al., 2021; Izarra et al., 2021). Polyurethane foams are also a type of polymer material with a cellular structure. For this reason, they are also classified as open-cell and closed-cell foams. Rigid polyurethane foams have a lower density and a closed-cell structure, while flexible polyurethane foams have an open-cell structure (Polaczek et al., 2022; Salino & Catai, 2023). In general, no foam has a completely uniform cell structure.

Today, noise pollution has become a significant environmental problem with industrial developments and advances in transportation. Especially automobiles bring about various sources of noise pollution such as engine noise and structural noise caused by contact with the road. The automotive industry has various sound insulation standards and targets in order to increase in-car comfort and reduce noise levels.

In previous studies on sound insulation materials, PU foams are widely used and their acoustic performance is increased by reinforcing them with various fillers. Porous materials absorb sound energy and play an important role in increasing acoustic performance. Rigid polyurethane foams in particular are used as heat and sound insulation materials in construction and automotive industries (Rastegarfar et al., 2018). In the literature, studies have been conducted on foams produced with different NCO/OH ratios, foams prepared using different types of polyols, and organic and inorganic additives added to a fixed NCO/OH ratio (Coman et al., 2021; Izarra et al., 2021). In order to improve the sound insulation and sound absorption properties of polyurethane foams, Chen and Jiang (2016) used biodegradable and easily disposable natural bamboo leaves (bamboo particles and bamboo stems), while Ekici et al. (2021) added tea leaf fibers and luffa cylindrica, Zhu et al. (2019) and colleagues added various amounts of polyethylene fibers to PU foams (Chen & Jiang, 2016; Ekici et al., 2012; Zhu et al., 2019). Thermal, mechanical, and morphological analyses of the foam were carried out when cellulose, chitosan, hazelnut shell, and egg shell additives were added to the polyurethane foam at different rates (Husainie et al., 2021). There are studies showing how natural fibers such as Bambara Shell and Corn Husk, Coconut Shell and Corn Cob, Walnut and Hazelnut Shell improve various properties of PU foams and provide different effects depending on the type of these fibers (Kuranchie et al., 2021).

As waste is increasing day by day, ecological balance is being disrupted, global warming is increasing, and air and soil are being polluted. These negatively affect the lives of all living beings, especially humans, and also have negative effects on the economy. Fighting global pollution has become one of the greatest goals of scientists (Aguilar-Jurado et al., 2019; Ahmed & Rana, 2023; Bildirici & Gökmenoğlu, 2017; Butler, 2018; Marsolea Cristea et al., 2023; Nava-Castro et al., 2019; Terro, 2006; Triassi et al., 2015). With the Zero Waste project, which was opened in Turkey in 2017 and entered into force upon publication in the Official Gazette in 2019, wastes have been classified (plastic, paper, glass, metal, etc.) in many public and private institutions and organizations, and their recycling has gained importance (Türkiye Cumhuriyeti Çevre, 2024). Glass, which is resistant to many chemicals, high temperatures and oxidation, is a good alternative to plastic bottles because it is healthier. The increase in demand for glass products has also led to a significant increase in glass waste. Glass, one of the materials we use almost every day, takes approximately 4000 years to decompose in nature due to its chemical structure and durability. Glass is mainly made of silica and thus is a material that is not biodegradable in nature but it is 100 % recyclable. Glass waste can be recycled infinitely without losing its properties and functionality during recycling. When 3000 standard glass bottles are recycled, 1000 kg of waste accumulation is prevented and with each ton of recycled glass, 670 kg of carbon dioxide is prevented from being released from the atmosphere. Recycling glass waste in glass production reduces both air pollution by 20 % and greenhouse gas emission. In addition, the use of glass waste in glass production improves drinking water quality by approximately 50 %, which reduces the risk of infection and chemical poisoning. Glass recycling reduces the consumption of natural resources such as sand, limestone, sodium carbonate. Recycled glass has a lower melting point, which saves 26.6 % of energy. For every ton of glass recycling, 136 liters of oil are saved (Aguilar-Jurado et al., 2019; Consulting, 2010; Marsolea Cristea et al., 2023).

In addition to the reuse of glass waste in glass production, waste glass has found different areas of use in the literature, especially in the construction sector. Uzun et. al. (2018) and his friends used glass waste instead of cement because the chemical structures of glass and cement are similar and they observed that the compressive strength of concrete increased with the use of glass (Uzun et al., 2018). Glass waste used instead of aggregates in concrete (up to a certain percentage) improved the mechanical strength of concrete (Subhani et al., 2024). Najla Postaue and her friends used potassium fluoride / glass waste catalyst in biodiesel synthesis and observed that the catalyst used was efficient and increased the production of by-products, especially glycerin (Postaue et al., 2024). Glass powder was added to raku glaze recipes instead of ceramics, which are structurally and functionally similar, and the usability of glass powder as a raw material was proven (Sönmez, 2020).

In this study, polyurethane foams, which are used in many different areas, especially in the automotive industry, were produced with different ratios of waste soda glass powder by keeping the isocyanate/polyol ratio constant. While soda glass is known for its high sound absorption capacity and low density properties, we aim to increase the acoustic properties of polyurethane foams. This research is important in two critical aspects. The first is to emphasize the importance of recycling in protecting human health and natural resources and to support environmental sustainability. The second is to fill the current knowledge gap in automotive sound insulation in order to reduce noise in vehicle interiors and increase driving comfort. Previous studies have focused on different fillers and chemical structures to increase the sound absorption properties of PU foams. However, the potential of soda glass in PU foams and its ability to increase sound absorption capacity stands out as an area that has not yet been investigated. The research is expected to fill the current knowledge gap in automotive sound insulation and to provide a new perspective in this field.

The chemical composition of soda glass is given in Figure 1.

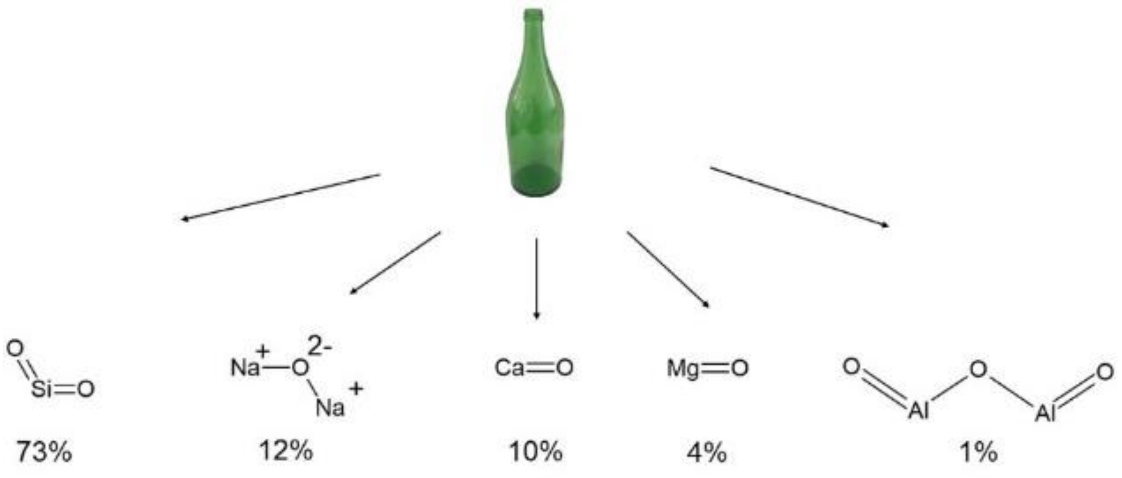

Figure 1. Chemical composition of soda glass.

The contact angle, fourier transfer infrared spectroscopy (FT-IR), sound transmission loss and density measurements of the produced foams were performed.

2. Material and method

The raw materials of polyurethane foams, polyol component and iso component, were supplied by BASF. The polyol component is a mixture containing polyol, catalyst, additives. The iso component contains the chemical methylenediphenyldiisocyanate (P-MDI). The physical properties of the iso component and polyol component are given in Table 1.

Table 1. Component datas of polyol component and iso component.

	Density (g/cm^3)*	Viscosity (mPa.s)*	NCO content (%)
Polyol component	1.04	1000	-
Iso component	1.23	50	32

*Density and viscosity values arevrecorded at 25 °C.

Green soda glass was purchased from a local market in Turkey. Polyol component, iso component and soda glass were used as received.

The isocyanate/polyol (-NCO/-OH) ratio is critical in RPUF synthesis. When the isocyanate/polyol (-NCO/-OH) ratio is equal to 1, a reaction occurs at equilibrium. In order for all polyol groups to react, an excess of the isocyanate group must be used. When the isocyanate/polyol (-NCO/-OH) ratio is greater than 1, highly cross-linked rigid polyurethane foams will be formed (Akindoyo et al., 2016; Das & Mahanwar, 2020; Wang et al., 2023). In this study, the -NCO/-OH ratio was determined as 1.3 for rigid polyurethane foam production.

Waste soda glass was ground in a Pulverisette brand vibrating cup mill at 1000 rpm. Then, the soda glass powder was dried in a 100 ºC oven for 24 hours to remove moisture. The dried powders were sieved to separate large powder particles, and the particle size of the fine particles sieved through a 100 micron sieve was measured with a particle size determination device. The analysis was carried out in water and the measurement was taken with the laser diffraction method. The particle size distribution of the powder is given in the Table 2 with Dv10, Dv50, Dv90 and Dv99 values. When the obtained values were examined, the median value, Dv50, was found to be 32.7 µm. This value indicates that half of the particles are smaller than this size, while the other half are larger than 32.7 µm. The Dv90 value of 46.7 µm indicates that 90 % of the particles are smaller than this size.

Table 2. Particle size distribution of waste soda glass powder*.

Dv10	Dv50	Dv90	Dv99
12.23	32.7	46.7	60.1

* Dv values are presented in µm.

For the production of polyurethane foam, the required amount of polyol component was weighed and mixed with a mechanical mixer for 1 min. Then, 1 %, 2 %, 3 %, 4 %, 5 % (w/v) moisture-removed soda glass powder was added to the polyol component and mixed until a homogeneous mixture was obtained. The iso component was added to the homogeneous mixture and mixed at 2000 rpm for 10 seconds. The resulting mixture was quickly poured into a 30 cm x 30 cm x 4 cm container. The curing process of the obtained polyurethane foams was carried out for 48 hours at room conditions. Neat polyurethane foam was obtained by directly adding the iso component onto the homogeneous polyol component. The stages of the experiment are shown in the Figure 2 and the definitions of the produced rigid polyurethane foam samples are given in Table 3.

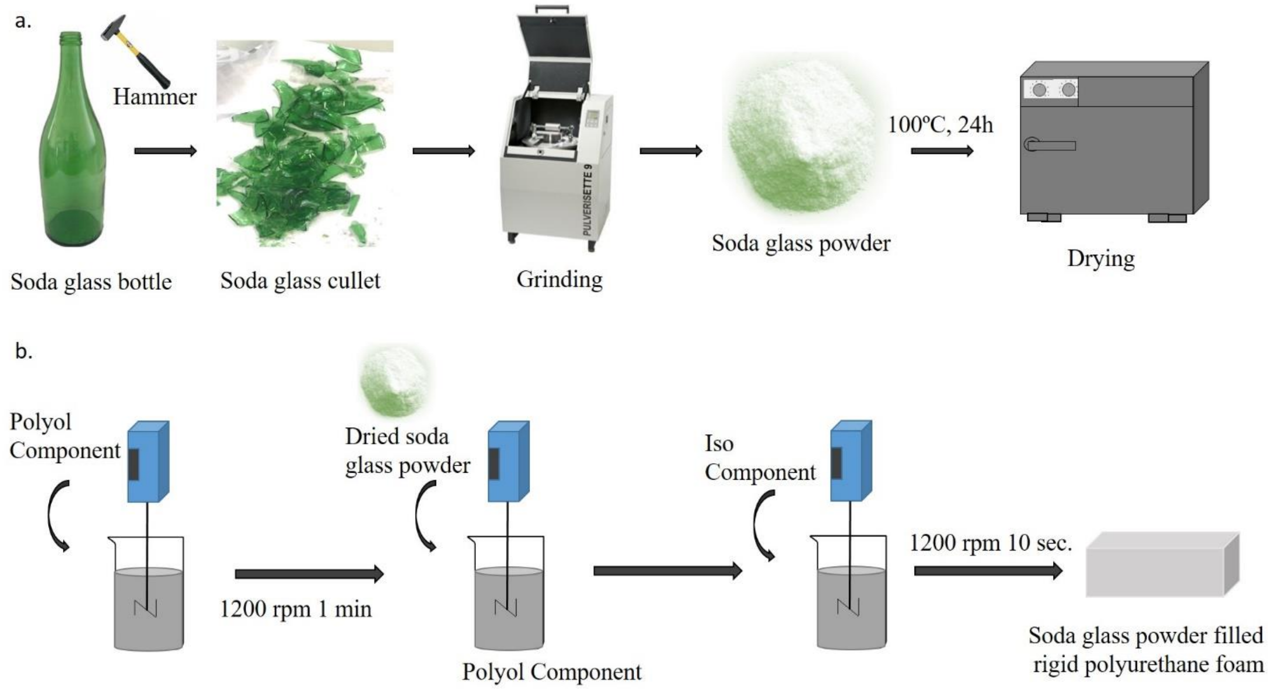

Figure 2. a) Stages of preparing the soda glass bottle for the experiment, b) Foam production scheme.

Table 3. Description of rigid polyurethane foams.

Symbol	**Description**
PU	Unfilled rigid polyurethane foam
PU-SG1	1 % soda glass powder filled rigid polyurethane foam
PU-SG2	2 % soda glass powder filled rigid polyurethane foam
PU-SG3	3 % soda glass powder filled rigid polyurethane foam
PU-SG4	4 % soda glass powder filled rigid polyurethane foam
PU-SG5	5 % soda glass powder filled rigid polyurethane foam

2.1. Analysis

FT-IR analysis was performed to observe the chemical bonds, functional groups, and interactions between soda glass powder and polyurethane. For the analyses performed in the 400-4000 cm^{-1} wavenumber range, 16 scans at 4 cm^{-1} resolution Transmission mode, a diamond crystal ATR head FT-IR spectrometer (Perkin Elmer/Spectrum Two) was used.

A contact angle device was used to determine the wettability of filled and unfilled foam samples. Contact angle measurements of 2 cm x 2 cm samples were performed in the contact angle device (Attension/Theta Lite) using distilled water in sessile drop mode.

Apparent densities of polyurethane foams were performed in three replicates for each sample according to the ASTM-D1622:20 “Apparent Density of Rigid Cellular Plastics” standard, and the average values of apparent densities were given (International, 2020).

$$d = \frac{m}{V} \tag{1}$$

Apparent densities were calculated according to Formula 1. d is the density of the foams in kg/m^3, m is the mass of the foams in kg, V is the volume of the samples in m^3.

The sound transmission loss properties of the obtained rigid foam samples were measured and calculated using the transfer function method in accordance with the ASTM E2611:19 "Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method" standard. The inner diameter of the impedance measurement tubes is 100 mm and 30 mm. Sound transmission loss measurements were carried out in the range of 50-6400 Hz (International, 2024).

3. Results and discussion

3.1. Apparent density

The apparent densities of soda glass powder filled and unfilled rigid polyurethane foams are given in Table 4. When the table is examined, it is seen that the apparent densities of unfilled foams are 38.25 kg/m^3. The apparent density of the foams increases with the addition of soda glass powder. The increase in apparent density when fillers are added to polyurethane foams is a result consistent with the literature (Członka et al., 2020; Głowacz-Czerwonka et al., 2023).

Tablo 4. Density results of polyurethane foams.

Sample	Density (kg/m^3)*
PU	38.25±0.33
PU-SG1	39.60±0.31
PU-SG2	39.98±0.35
PU-SG3	40.46±0.31
PU-SG4	42.87±0.32
PU-SG5	44.47±0.33

*Results are presented in mean ± standard deviation format.

3.2. Contact angle (WCA)

The contact angle is a test method in which apolar or polar liquid is dropped onto a surface to be analyzed and the angle formed between the surface and the dropped liquid is determined. It is an important analysis to observe the wettability quality of the solid surface. The angle formed between the solid surface and the liquid provides information about the hydrophilicity of the surface. If the contact angle is close to 0 degree, it is called superhydrophilic; if it is between 0 and 90, it is called hydrophilic; if it is between 90 and 140, it is called hydrophobic; and if it is higher than 140, it is called superhydrophobic. The size of the angle depends on the type of solid surface in contact, the type of liquid contacted and the cohesion-adhesion forces formed between them (Chau et al., 2009; de Oliveira et al., 2022).

The contact angle images of rigid nanocomposite foams are given in Figure 3.

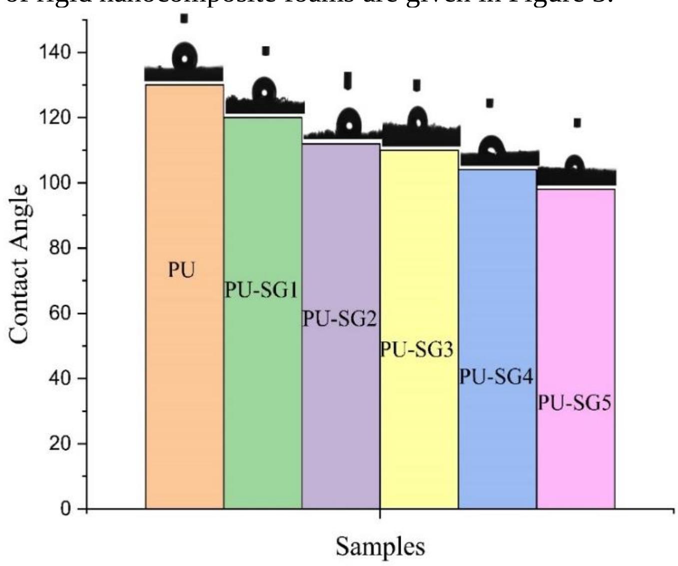

Figure 3. Contact angle graph of samples.

When the contact angle data were examined; it was observed that the contact angle values of soda glass powder filled and unfilled rigid polyurethane foams were above 90°. As a result of the measurements made with pure water, it was determined that the composite rigid foams produced had hydrophobic surfaces. The contact angle values of the rigid foam samples decreased as the soda glass doped ratio increased. This decrease can be explained by the hydrophobic structure of the glass (Ersoy et al., 2022; Jing et al., 2022).

High contact angles increase water resistance and ensure the longevity of materials, while also having a significant impact on acoustic performance. In the literature, it has been found that the water-repellent properties of materials are directly related to their ability to absorb sound energy (Chen et al., 2016; Ekici et al., 2021). In particular, it has been observed that polyurethane foams with high contact angles prevent water from accumulating in the pores within the material, increasing the absorption of sound waves by the material. This can contribute to the improvement of sound insulation performance (Zhu et al., 2019).

Research emphasizes the importance of establishing a balance between the porosity and waterproof properties of sound insulation materials; therefore, it is expected that the acoustic performance of materials with high contact angles will be increased (Rastegarfar et al., 2018).

3.3. Fourier transfer infrared spectroscopy (FT-IR)

The FT-IR spectra of rigid foam samples are given in Figure 4. Polyurethane foams are produced by the formation of urethane bonds as a result of the reaction of polyol and isocyanate raw materials. When the FTIR spectrum is examined, the presence of –N-C=O groups belonging to the isocyanate structure is seen at 2274 cm^{-1}. This shows that the isocyanate raw material is present in the environment and does not react completely. This is an expected result since the -NCO/-OH ratio is 1.3.

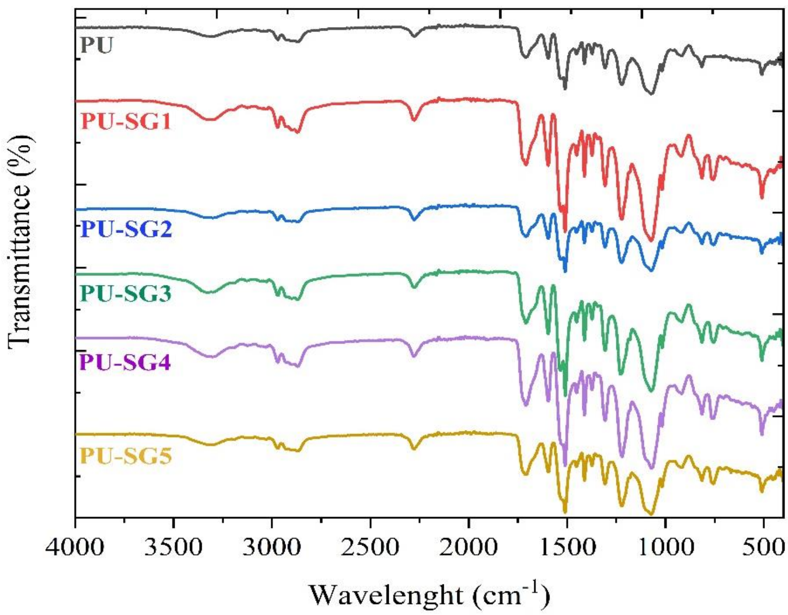

Figure 4. FT-IR spectrum of soda glass powder filled and unfilled rigid polyurethane foams.

The broad peak located at 3317 cm^{-1} shows the stretching vibration mode of –N-H bonds of H-bonded urethane groups. The peaks located at 2965 cm^{-1} and 2862 cm^{-1} are asymmetric –C-H and symmetric –C-H stretching vibration peaks, respectively. The peak located at 1714 cm^{-1} is the –C=O stretching vibration peak of ester groups. The peak located at 1593-1538 cm^{-1} is the –C=C stretching vibration peaks of benzene rings from the isocyanate structure. The peaks located at 1507 cm^{-1} and 1226 cm^{-1} are the stretching vibration peaks of –N-H (amide II and amide III) bonds, respectively. The symmetric and asymmetric stretching vibration peaks of –C-O-C bonds are located at 1063 cm^{-1} and 1013 cm^{-1} (Dzunuzovic et al., 2024; Maamoun et al., 2024; Marsolea Cristea et al., 2023). The absence of change in the main peaks of polyurethane in unfilled and soda glass added polyurethane foam samples explains that the addition of soda glass powder does not react chemically with the structure in the formation of polyurethane. In rigid polyurethane foam samples with soda glass added, the peak at 1006 cm^{-1} is attributed to the asymmetric stretching of Si-O-Si bonds, the peak at 820 cm^{-1} is attributed to the symmetric stretching of Si-O bonds, and the peak at 770 cm^{-1} is attributed to Silica bonds (Marsolea Cristea et al., 2023).

3.4. Sound transmission loss

Sound that spreads in waves in the environment is a type of energy. Sound waves spread through molecules in the air or through structural elements (e.g., the vehicle body). Sound transmission loss is a parameter that measures how much a material blocks sound energy in the direction of transmission and is usually measured in decibels (dB). High transmission loss effectively prevents the transmission of sound and thus increases acoustic comfort. Sound transmission loss is measured by the Impedance Tube Method and Reverberation Chamber Methods. The Impedance Tube Method is used to measure the sound absorption coefficient and transmission loss on the material. Large diameter tubes are used especially at low frequencies and small diameter tubes are used at high frequencies (Chen et al., 2015; Cunha et al., 2022; Zhu et al., 2019; Zhu et al., 2023).

Sound transmission mechanism and sound transmission loss are of critical importance in providing acoustic comfort in automotive industry as in many areas. In automotive industry, sound transmission loss is of great importance in terms of increasing in-car acoustic comfort and reducing external noise. In-car noise can be caused by the engine, road and environment, and reducing these sounds increases comfort for the driver and passengers (Koru et al., 2020; Ceyhan et al., 2021).

Especially in automotive industry, sound insulation methods are constantly being developed to reduce costs and increase performance, and virtual and analytical methods are gaining importance in this process. Research is focused on the development of materials and structures that will increase sound transmission loss.

The sound transmission loss results of the produced composite rigid foams are given in Figure 5.

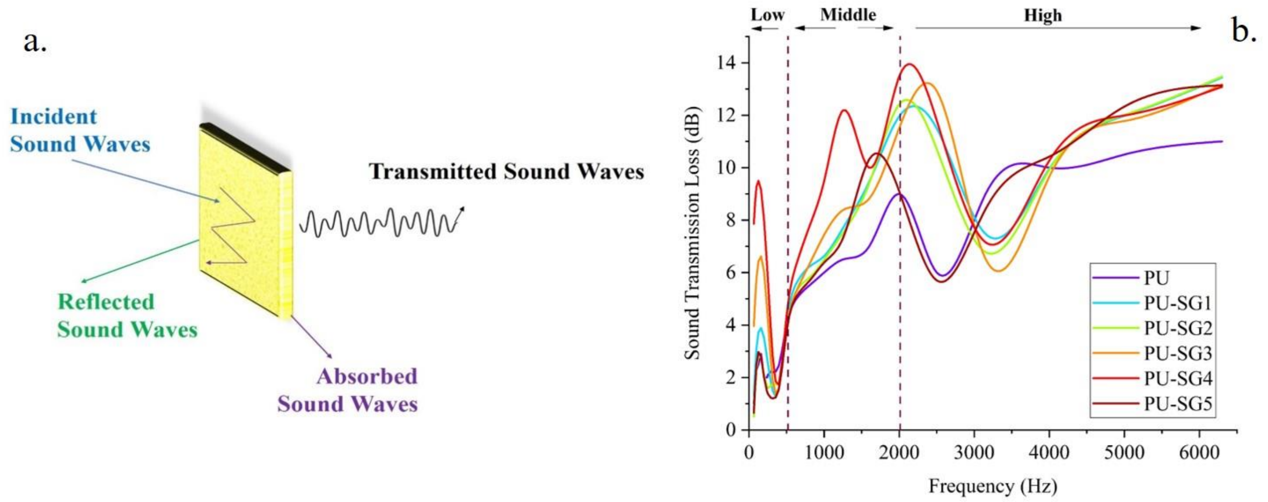

Figure 5. a) Sound transmission mechanism, b) Sound transmission loss graph of composite foam samples.

As seen in Figure 5b, the sound transmission loss values of polyurethane foams with different ratios of soda glass powder are higher than the neat PU sample in almost all frequency ranges. In the low frequency range region (20-250 Hz), the sound transmission loss of the neat PU sample was measured as 2.9 dB, while the sound transmission loss of the PU-SG4 coded sample was measured as 9.28 dB. In the middle frequency range region (250-2000 Hz), the sound transmission loss of the neat PU sample was measured as 9.1 dB, while the sound transmission loss of the PU-SG4 coded sample was measured as 13.48 dB. In the high frequency range region (2000-6300 Hz), the sound transmission loss of the neat PU sample was 11 dB, while all of the foam composites with soda glass additives reached a sound transmission loss above 13 dB. The sound transmission loss increases as the soda glass powder additive increases (except PU-SG5). The obtained data show that the soda glass additive increases the sound transmission loss value of the foam samples.

In order to increase the acoustic performance of polyurethane foams, fillers are generally preferred to absorb the sound energy emitted during the propagation of sound waves (Sung et al., 2016). Orfali (2015) observed an increase in sound absorption at low rates such as 0.2 % and 0.35 % by adding different rates of carbon nanotubes and nano-silica to the foams, while it was noted that this effect decreased at a rate of 2 %. This situation was explained by the fact that the fillers prevented the formation of the appropriate cell structure by preventing the interaction between polyol and isocyanate. Choe et al. (2020) and colleagues emphasized that the sound absorption coefficients of PU foams increased with the addition of calcium carbonate filler material, but rates above 6 % could decrease the sound absorption efficiency by increasing the open porosity. High open porosity can reduce the impact of sound waves with cell walls by reducing the interactions with air molecules. In another study, it was stated that magnesium hydroxide filler material provided optimum open porosity at 1.0 %, but higher rates decreased acoustic efficiency. This was explained by the fact that excessive amounts of filler material disrupted the internal structure of the cells and made it difficult for sound waves to pass (Sung et al., 2016). In all three studies, sound absorption properties increased with the addition of filler materials, but this increase stopped after a certain rate and sound absorption values even decreased. This situation was explained by some physical interactions that occurred with the increase in the amount of filler materials. Adding more than 4 % (w/v) waste soda glass could also be a threshold value for the produced composite foam sample. The filler material may have facilitated the passage of sound waves by preventing the reaction between polyol-isocyanate or by increasing porosity.

4. Conclusions and recommendations

This study aims to improve the acoustic properties of rigid polyurethane foams used as insulation materials in many different industrial areas, while evaluating wastes that have negative effects on ecological balance and economy. The mixture of iso component and polyol component was used for composite foam production. Isocyanate/polyol ratio was selected as 1.3.

-Excessive isocyanate causes the foam to be rigid. FT-IR results confirm this situation and that soda glass powder and polyurethane do not chemically react.

-Increasing soda glass powder additive increases the apparent density values of the foams.

-Contact angle results show that rigid polyurethane foams exhibit hydrophobic properties, and as the additive ratio increases, the contact angle values decrease due to the hydrophilic structure of the glass.

-Sound transmission loss results in low, medium and high frequency range regions show that the additive foam samples have acoustic properties compared to the neat PU sample.

-Sound transmission loss of the additive foam samples exceeds 13 dB in the high frequency range region.

The study results show that the acoustic performance of porous polyurethane foams can be significantly improved by using recycled waste glass powder, providing economic and sustainable benefits.

The long-term durability of foams against different environmental conditions (humidity/temperature cycles) is a critical factor in real-world applications. Optimization of filler content and performance tests under different environmental conditions are planned for future studies.

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Author contribution

The planning, execution of the experimental studies, interpretation of the results and writing of the article were done by the corresponding author. The author has read and approved the final version of the manuscript.

Declaration of ethical code

The author declares that the materials and methods used in this study do not require ethics committee approval and/or special legal permission.

Conflicts of interest

The author declares no competing interests.

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