Journal of Elementology ISSN 1644-2296

Özocak, M. and Sisman, C. (2024) 'Development of a new insulation material from hazelnut shells (Hazelnut shell insulation board – HSIB)', *Journal of Elementology*, 29(1), 293-310,
available: https://doi.org/10.5601/jelem.2024.29.1.3187

RECEIVED: 2 January 2024
ACCEPTED: 14 February 2024

ORIGINAL PAPER

Development of a new insulation material from hazelnut shells (hazelnut shell insulation board – HSIB)*

Murat Ozocak[1], Can Burak Sisman[2]

**[1] Plant and Animal Production Department
Istanbul University-Cerrahpasa, 34473 Bahçeköy, Istanbul, Turkey
[2] Biosystems Engineering Department
Tekirdağ Namık Kemal University, Tekirdağ, Turkey**

Abstract

Environmental pollution caused by waste is constantly increasing. In this context, waste disposal efforts have gained importance. Among possible solutions, the disposal of waste by converting it into a new product stands out. In addition to preventing environmental pollution, it is also possible to obtain a new product by utilizing wastes, especially generated by agricultural production. A new insulation material (HSIB) has been developed from hazelnut shells used in different proportions. The aim of this study has been to produce insulation boards by using the shells released as waste after hazelnut production. For this purpose, 5 mm thick insulation boards were made by gluing very fine-grained (0-4 mm) hazelnut shells with epoxy and pressing. Two separate types of board were formed, composed of 80% and 90% of the hazelnut shells and 20% and 10% epoxy as binder, respectively. Thermal conductivity, sound transmission, water absorption, unit volume and compressive strength tests were carried out on both board types. The results showed that the unit volume weights of the boards were 1.543-1,592 g cm^{-3}, thermal conductivity coefficients were 0.136-0.148 $W(m.K)^{-1}$, and sound transmission velocities were 1196-1270 m s^{-1}. Thermal conductivity and sound transmission values have a strong linear correlation with volume. Within the scope of the research, it can be said that the insulation board (HSIB) developed by using hazelnut shells, which are agricultural waste, can be used to improve thermal insulation in different parts of buildings, such as walls and ceilings.

Keywords: hazelnutshell, waste evaluation, building material, insulation material, thermal insulation, sound insulation, thermal conductivity

Murat Ozocak, PhD, Plant and Animal Production Department, Forestry Vocational School, Istanbul University-Cerrahpaşa, Irrigation Technology Program, Valide Sultan Street No: 2-34473 Bahceköy-Sariyer, İstanbul, e-mail: muratozocak@iuc.edu.tr
* The authors did not receive any financial assistance during the research and writing phase of the article.

INTRODUCTION

Fossil fuel resources, consumed in large quantities as a result of the demand for energy, are being depleted day by day. This aggravates environmental pollution. The increase in energy consumption and environmental pollution is a major problem of the 21st century (De Wilde, Van der Voorden 2004). People have become dependent on the use of these fossil fuels, enduring the environmental pollution it contributes to (Brundtland 1987).

Insulation, which means insulating against external effects, is defined as use of building materials that prevent damage to living organisms and goods housed in buildings. Insulation first started when people wrapped themselves in the skins of animals they hunted in order to protect themselves from external environmental conditions, and developed in the course of history as the protection of firstly people and then places. In real sense, insulation was used in steam boilers in the 19th century, and later on, insulation was developed to protect from cold as well as heat. In 1882, Carl Von Linde made the first study on long-term storage in cold storage rooms. The materials found as a result of these studies are generally defined as insulation materials (Karakoç et al. 1999).

Insulation is recognized as a simple yet highly energy efficient technology that can be applied in residential, commercial and industrial sectors. The material that provides thermal insulation consists of a material or composite materials with high thermal resistance properties that demonstrate the ability to reduce the heat flow rate (Al-Homoud 2005). In this context, building insulation can keep the heat/cold inside the house and prevent heat flow mixing with the environment (Al-Sallal 2003).

In today's conditions, the demand for energy is increasing rapidly as a result of the population growth, industrialization, industrial activities and urbanization. This situation stimulates both the demand for energy and energy consumption. In addition, increasing energy consumption causes serious harm to human and environmental health. When evaluated in terms of commercial, industrial and residential buildings, it is seen that the most energy consumption is dedicated to heating or cooling purposes. This has brought thermal insulation work in buildings to the fore among efforts to reduce energy consumption. Heat losses in buildings can be prevented with the help of thermal insulation. In this context, the amount of energy used in buildings can be reduced by thermal refurbishment in buildings. In addition, by insulating buildings, energy consumption will be reduced, as well as the emission of carbon dioxide, sulfur dioxide and other harmful gases that may spread into the atmosphere (Şenkal Sezer 2005).

There are many types of materials used for thermal insulation in buildings. Materials for insulation purposes can be generally examined in four different categories. These materials can be listed as inorganic materials, organic materials and combined materials as well as new technology materials. Inorganic insulation materials are ceramic-based materials such as fibrous, calcium silicate, perlite, glass, stone and slag. Organic insulation materials are materials such as cellulose, cotton, wood, paper pulp, foamed rubber, polyethylene and polyurethane. Combined materials are silicone and gypsum-added materials, and new technology materials can be classified as transparent and dynamic materials (Papadopoulos 2005).

The main parameter that indicates the thermal performance of a material for insulation purposes is the heat conduction coefficient. The unit of heat conduction coefficient is W(m.K) -1 and it is defined as the heat flow passing through the unit area of a material. Determining the heat conduction properties alone is not sufficient for materials to be used for insulation purposes. Providing successful insulation is possible by evaluating many variables, such as thermal performance, strength, unit volume weight, pressure resistance, economy, water absorption percentage, sound transmission rate, fire resistance and ease of application. In addition to thermal properties, determining the sound transmission rate contributes to the value of insulation in terms of acoustic comfort (Arslan, Aktaş 2018).

There are many studies on the use of agricultural waste materials in order to ensure energy efficiency in buildings. Of these studies, Mati-Baouche et al. (2014) developed a new insulation board using sunflower stalk and chitosan. As a result of the study, insulation material with low thermal conductivity values was obtained. In other studies on sunflower origin materials, Evon et al. (2014), Binici et al. (2014) developed an insulation material with a low thermal conductivity coefficient. In another study, Khedari et al. (2003) and Khedari et al. (2004) developed a wall and ceiling insulation material with low thermal conductivity properties using coconut and durian shells. Xu et al. (2004) created an insulating material from kenaf core. In another study using corn husk and paper production waste, Lerttsutthiwong et al. (2008) obtained insulating material with low thermal conductivity properties. Panyakaew and Fotios (2011) produced insulation boards using coconut shell and pulp. Zhou et al. (2004) developed insulation material using wheat straw in a hollow form. In another study, Zhou et al. (2010) obtained insulation material with low thermal conductivity by using cotton straw. Excellent results have been obtained in terms of energy saving and insulation, especially with the use of this building material on building walls. In a study using peanut shell and coconut fiber, it was concluded that both agricultural wastes could be used as insulation material (Cravo et al. 2014). Korjenic et al. (2011) has developed a thermal insulation material based on flax, hemp and jute. In addition, it has been demonstrated by different studies that various agricultural wastes such as olive seed kernels, date fibers, wheat straw can be used in buildings for purposes of insulation and energy saving (Khedari et al. 2001, Ashour et al. 2010, Barreca, Fichera 2013, Chikhi et al. 2013, Belhadi et al. 2014, Djoudi et al. 2014).

Hazelnut is the fruit of the hazelnut tree (*Coryllus avellana* L.). It originated in Anatolia and Greece and spread to Europe in the 19th century. The largest hazelnut producing countries in the world are Türkiye, Azerbaijan and the United States. Hazelnut is a fruit that is produced in the amount of around 1.1 million tons over about 1 million hectares of planting area in the world; it is consumed as whole hazelnuts, but also commonly used in pastry, halvah, sweets and especially in the chocolate industry. Approximately 60% of the world's annual hazelnut production is carried out in Türkiye, with 700 thousand hectares of planting area and 670 thousand tons of production (Demir, Beyhan 2000).

Türkiye's hazelnut production area in 2022 was 7.4 million, and the total hazelnut production amount reached 765 thousand tons. When evaluated for the 10-year period between 2012 and 2022, there was a 6% increase in the total production area. At the same time, there was a 16% increase in the total production amount. Considering the last two years, hazelnut production in Türkiye in 2021 was 684 thousand tons, and it increased by 11.8% in 2022, reaching 765 thousand tons. When hazelnut production in Türkiye is evaluated in terms of provinces, it is seen that Ordu province is in the first place with 240 thousand tons. Samsun province is in second place with 112 thousand tons, and Sakarya is in third place with 98 thousand tons. Regionally, the most important region is the Black Sea Region. 85% of the total hazelnut production in Türkiye is carried out by this region (Bars 2023).

When evaluated from the economic perspective, Türkiye ranks first in the world in terms of hazelnut production, production area and export values. With this location, it provides a significant foreign exchange inflow to the country's economy. 75% of exports are to the EU countries. Türkiye's hazelnut exports in the 2021/2022 period were 732 thousand tons. Italy is one of the leading countries to which Türkiye exports hazelnuts. In 2022, 54 thousand tons of hazelnuts were exported to Italy, 45 thousand tons to Germany and 13 thousand tons to France (Bars 2023).

When the relationship between hazelnut production and yield in Türkiye is examined, it is seen that production and yield are varied in different amounts between regions. At the same time, fluctuations occur over the years within regions. This situation generally varies due to climatic environmental conditions and the periodicity of hazelnuts (Ömür 2023). As a result of hazelnut gardens being established in earlier years and the production area being denser, Kocaeli, Sakarya and Düzce provinces have higher yields than Ordu, Trabzon and Giresun provinces. (SPO 2021). This situation is due to the fact that the majority of hazelnut orchards in the Eastern Black Sea Region of Türkiye were created 50-100 years ago, and the climatic conditions and maintenance procedures were inadequate. In addition, the measures to be taken against vegetative diseases that may reduce the yield in hazelnut cultivation in the provinces of these regions need improvement (Bars 2021).

The hazelnut shell is the most important waste that occurs in hazelnut production, as it makes up approximately 50% of the nut. Different researchers have studied the chemical composition of the hazelnut shell (Demirbaş 2003). Based on the results and according to Demirbaş (2003), it contains approximately 30% hemizcellulose, 26% cellulose and 43% lignin. In another study, it contains 25% hemicellulose, 37% cellulose and 23% lignin (Saura--Calixto et al. 1983).

Considering the hazelnut production in Türkiye, the annual amount of shells is around 300 - 330 thousand tons. The use of shells, which are produced in significant quantities, as raw materials in different sectors eliminates problems such as transportation and storage, while at the same time preventing environmental problems. Today, hazelnut shells are used in the USA and some European countries in the production of paint, linoleum and contralite boards. In addition to these uses, it is a potential material that can be processed especially in the production of insulation boards due to its fibrous structure and the hollow structure it creates when milled (Hoşgün, Bozan 2017, Özocak, Şişman 2020). In this context, it will be possible to use hazelnut shells, which is an agricultural waste, in buildings by turning them into a new material for insulation purposes. In this study, a new insulation material from hazelnut shells that can be used in buildings was developed. The density, thermal conductivity, sound insulation, water resistance and mechanical properties of the sheets produced using different amounts of hazelnut shells and epoxy resin in the developed material were investigated. Statistical analyses of the experimental results obtained were carried out and statistical relationships between different experimental variables were revealed.

MATERIALS AND METHODS

Material

Within the scope of the research, hazelnut shells and insulation board samples produced with epoxy resin constituted the material of the study. Mechanical, physical and thermal experiments were carried out on the produced insulation board samples. The hazelnut shells for this experiment were obtained from the waste material generated in hazelnut processing facilities after the harvest of hazelnut fruit in Giresun province in the Black Sea Region of Türkiye. Epoxy resin was supplied from Duru Chem Dupoks Chemical as a transparent colored set consisting of resin and hardener. The insulation board samples that constitute the material of the study were produced by molding hazelnut shells of a certain size under pressure and mixing with two different amounts of epoxy resin.

METHODS

Preparation the hazelnut shell

The hazelnut shells were ground to a grain diameter between 0-4 mm using the Los Angeles device given in Figure 1. The device is defined to correspond to TS-EN 1097-2 standards, and consists of a closed cylindrical

Fig. 1. Los Angles device and ground hazelnut shells

drum that can rotate along the horizontal axis on balls mounted on a solid steel basic frame (TSI 2010). The drum operates in a closed system at a speed varying between 30-33 rpm. The grain distribution of the shells to be used in insulation board production was determined by sieve analysis, and a distribution in accordance with the (TSI 2012) standard of the Turkish Standards Institute was created.

Manufacturing of insulation board from hazelnut shells (HSIB)

After the hazelnut shells used in the study were converted to a grain diameter range of 0-4 mm, the production phase of the insulation board samples was started. Epoxy resin was used as a binder in the research (Figure 2) Since the quality and amount of binder used in the production of insulation boards will create differences in the properties of the board, two different amounts of epoxy resin were used: 10% and 20% (HS10, HS20) of the hazelnut shell amount. Epoxy resin is a material with increased viscosity that hardens thanks to the paint consistency additive. Epoxy resin used as a binder has two components, a hardener and an epoxy gel, and as a result of mixing these two components, it gains very good adhesion properties (Qi et al 2006).

Epoxy resin is mixed with a number of agents that ensure hardening. As a result of this mixture, hardening and drying properties occur. Stable bonds that develop within the mixture enable the epoxy resin to gain strength. In addition, physical adhesion to the surface also occurs (Can 2008).

Fig. 2. Epoxy gel and binder

Epoxy resins show hardening properties as a result of their reactivity at room temperature. Hardening and drying times vary depending on the type of epoxy resin, type of hardener, environmental conditions and storage processes. The curing time of the resin mixture, which is completed as a result of hardening and drying, varies from a few hours to a few days, depending on environmental conditions and production characteristics (Temiz 2003). The epoxy resin used in the study was obtained from Dupoks company and was applied by mixing the hardener and epoxy gel in a 1:1 ratio. Epoxy transparent color was chosen to make the hazelnut shells stand out on the insulation panels produced. The epoxy used does not contain solvents and provides full hardening in 72-96 hours at room temperature, depending on production specifications. In this experiment, the hardener and epoxy gel poured into a different container were mixed and then poured into molds containing hazelnut shells and left to cure for 4 days. The chemical properties of the epoxy resin set used in the research obtained from the manufacturer and are given in Table 1.

15x15x15 cm standard cube molds shown in Figure 3 were used in the production of insulation board samples with hazelnut shell and epoxy resin. In order to prevent the epoxy resin and ground hazelnut shell from sticking to the mold, the inner surface of the mold is covered with nylon foil.

While molding, firstly the molds were filled with 5 cm thick ground hazelnut shells and the epoxy resin prepared was slowly added as much as the determined usage amount (HS10, HS20). After adding epoxy resin to the molds, it was allowed to dry for one hour and then a weight of 0.22 kg cm^{-2} was placed on each mold for the mold contents to harden under pressure, previously covering the top with nylon foil (Binici et al. 2014). In order for

Table 1

Chemical properties of epoxy resin

Structural characteristics	Two-component epoxy resin
Density	1.23 g cm^{-3}
Appearance/color	clear
Full cure	7 day (23°C - %50 moisture)
Min. curing temperature	8°C
Adhesion strength	2,5N mm^{-2}
Application temperature	8°C - 35°C
Water resistance	very good
UV strength	high
Na_2O	1.21
Loss of glow	3.34
Compressive strength	>30 N mm^{-2}
Heat resistance	-20°C - +145°C
First drying	4 h
Working time	45-55 min
Application temperature	5°C - 35°C

Fig. 3. Production of insulation board samples

the epoxy resin to harden completely, the insulation board samples were kept in the molds under pressure during the curing period; then they were removed from the molds and the testing phase began.

Thermal conductivity

Thermal conductivity coefficients were determined in order to identify the thermal insulation properties of the insulation board samples produced in the research. The heat transmission coefficient of the insulation boards was determined using the QTM-500 model thermal conductivity measuring device, in accordance with the hot wire method given in TSI (2013) and ASTM (1990) standards.

A thermal conductivity test was carried out at room temperature and in fully saturated conditions using a rapid thermal conductivity meter QTM 500 from Kyoto Electronics Manufacturing Company Ltd, which is employed to measure the thermal conductivity values of building materials. QTM-500 measures the thermal conductivity of various samples in block form or sheet form by means of a probe applied to the surface of the sample at uniform temperature. After the calibration measurements of the device were made before the experiment, the measurements of the thermal conductivity coefficients of the produced insulation board samples were completed. The QTM-500 device used to measure thermal conductivity has a limiting measurement range of 0.023 $W(m.K)^{-1}$ to 12 $W(m.K)^{-1}$ with an accuracy and repeatability of reading values of ±5% and ±3%, respectively. This technique is a reliable, effective and fast method of measuring thermal conductivity (Grubbe et al. 1983, Sass et al. 1984, Thienprasert, Raksaskulwong 1984, Demirbo'a 2003, Çanakci et al. 2007).

Mechanical and physical properties

In order to determine the physical and mechanical properties of the insulation board samples, ultrasonic sound transmission, unit volume weight, water absorption percentage and compressive strength tests were carried out. Ultrasonic sound transmission rates are calculated using the equation below by measuring the time that sound waves sent from one surface of the samples specified in TSI (1999) and ASTM (1994) standards reach the other surface.

$$V = (S\ t^{-1}) \cdot 106 \qquad (1)$$

where: V – ultrasonic sound transmission rates (m s^{-1}),
S – distance between the surfaces of the material (m), t = time (s^{-1}).

The methods given in the TSI (1981) standard were used to determine the unit volume weights and water absorption rates of the insulation board samples. The compressive strengths of the samples were determined using a hydraulic press in accordance with TSI (2019) standard.

Statistical analysis

Variance analysis was performed using the SPSS program in order to statistically evaluate the data obtained as a result of the thermal conductivity, physical and mechanical tests of the insulation board samples produced in the experiment. Variance analysis is used to compare the averages of two or more independent groups under one factor. Consequently, relationships between two or more variables are revealed (Ergun 1995).

RESULTS AND DISCUSSION

Two different insulation board samples named HS10 and HS20 with different hazelnut shell and epoxy resin ratios were produced, and both samples were subjected to the same tests. The thermal conductivity coefficient, ultrasonic sound transmission rate, unit volume weight, water absorption rate and compressive strength test results on the insulation board samples produced using ground hazelnut shells and two different amounts of epoxy resin are given in Table 2.

Table 2

Results of tests on insulation board samples

Mechanical and physical properties	HS10	HS20	Average	*P*
Thermal conductivity coefficient $W(m.K)^{-1}$	0.136	0.148	0.142	0.008**
Ultrasonic sound transmission rate ($m\ s^{-1}$)	1196	1270	1233	0.003**
Unit volume weight ($g\ cm^{-3}$)	1.543	1.592	1.567	0.003**
Water absorption rate (%)	11.29	9.23	10.26	0.006**
Compressive strength (MPa)	1.13	1.47	1.3	0.014*

The variation of the thermal conductivity coefficient values, which is the most important parameter of insulation boards produced for insulation purposes, depending on the amount of epoxy resin entering the mixture, is given in Figure 4. When the results were examined, it was determined that the

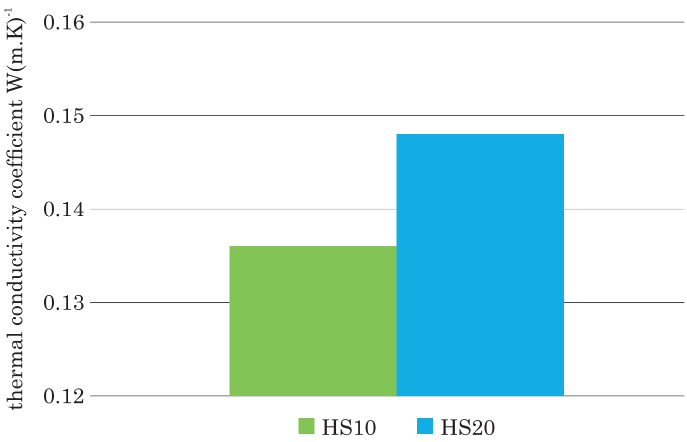

Fig. 4. Thermal conductivity coefficients of insulation board samples

higher amount of epoxy resin entering the mixture increased the thermal conductivity coefficient, and the thermal conductivity coefficient of HS20 was 8% higher than that of HS10. This is a result of the cured epoxy resin reducing the porosity formed in the insulation board samples due to its high void-filling properties (Çalışkan Değirmenci et al. 2015). When the variance analysis on the thermal conductivity coefficients was completed (Table 2), it was determined that the amount of epoxy resin entering the mixture created a statistically significant difference (P<0.01).

In order for any material to be identified as an insulation material, the thermal conductivity coefficient must be less than 0.065 W(m.K)$^{-1}$ as specified in the TSI (2013) standard, and the smaller the thermal conductivity coefficient, the better the insulation property. Although the boards produced in the research cannot be defined as heat insulation material according to the relevant standard, compared to other construction materials such as concrete, brick, aerated concrete and wood (pine), respectively λ: 1.80 - 0.44 - 0.17 - 0.15 W(m.K)$^{-1}$ – Toydemir, Gürdal (2011), it can be easily said that it has very high thermal insulation properties.

Ultrasonic sound transmission velocity measurements made in order to determine the sound insulation properties of the produced insulation board samples are given in Figure 5. In parallel with the results of the thermal conductivity coefficient, an increase in the ultrasonic sound transmission rate was observed as the amount of epoxy resin entering the mixture increased, and this increase was around 6% for HS20. As a result of the analysis of variance (Table 2), it was determined that this difference in sound transmission rate between HS10 and HS20 was statistically highly significant (P<0.01).

While the coefficient of thermal conductivity varies in direct proportion with the ultrasonic sound transmission rate and unit volume weight in a material, it correlates inversely with porosity (Karaağaç et al. 2016,

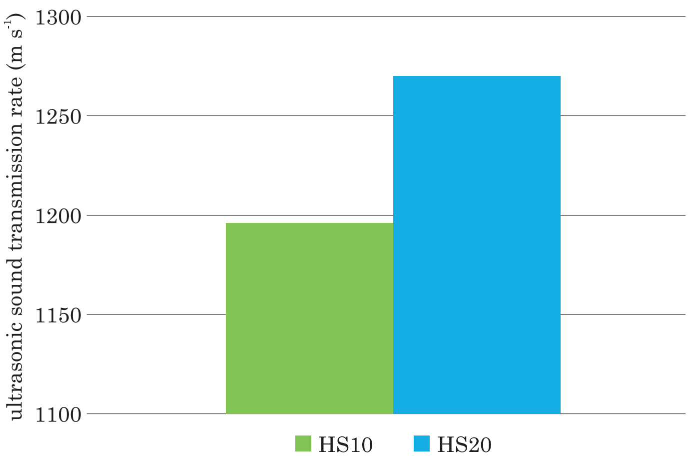

Fig. 5. Sound transmission velocities of insulation board samples

Özcan, Akçaözoğlu 2018). Therefore, as the amount of epoxy resin used in this study increased, the porosity decreased and the thermal conductivity coefficient and ultrasonic sound transmission rate increased.

The unit volume weights of the insulation boards produced using two different amounts of epoxy resin are given in Figure 6, and were determined

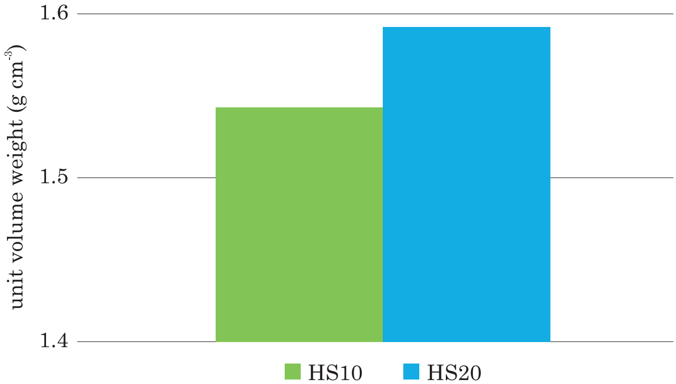

Fig. 6. Unit volume weights of insulation board samples

as 1.543 and 1.592 g cm^{-3}, respectively. As the amount of epoxy resin used increased, the unit volume weight increased by approximately 3%, and this difference was found to be statistically significant (P<0.01) according to the analysis of variance (Table 2). As expected, this increase in unit volume weights, as in the other parameters given above, was caused by a greater amount of epoxy diminishing the amount of voids and improving the filling.

When the water absorption rates of the insulation boards were examined (Figure 7), it was determined that as the amount of epoxy resin increased, the water absorption rate decreased and the water absorption rate of HS20 was 5% lower than that of HS10. This decrease in water absorption rates was due to the decrease in the void ratio in the insulation board samples, and the difference was found to be statistically significant (Table 2). Gene-

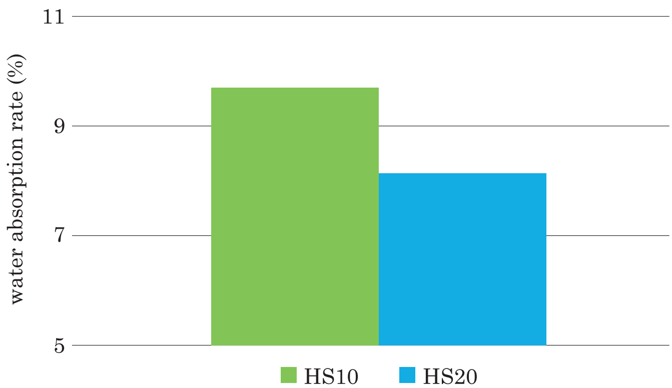

Fig. 7. Water absorption rates of insulation board samples

rally, water absorption percentages are high in the boards produced with natural materials of organic origin (Kymäläinen, Sjöberg 2008, Schiavoni et al. 2016). The water absorption percentages of the insulation boards produced from hazelnut shells were also high.

The results of compressive strength tests made on the insulation board samples developed in this experiment are given in Figure 8. Upon inspection,

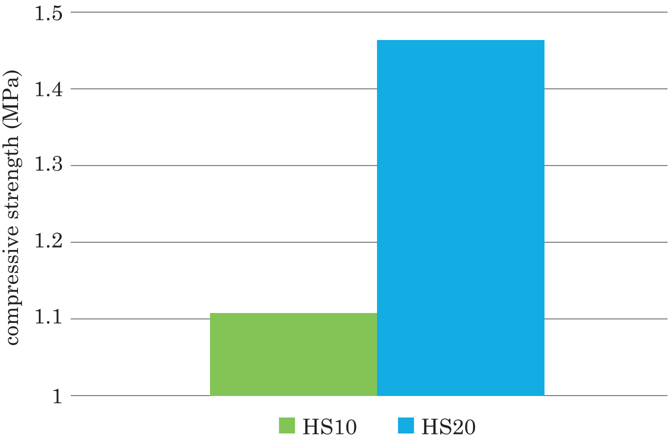

Fig. 8. Compressive strengths of insulation board samples

it is seen that the compressive strengths increased from 1.13 MPa for HS10 to 1.47 MPa for HS20, and the compressive strength increased by 30% as the amount of epoxy resin in the mixture increased. It was determined that this increase in strength created a statistically significant difference ($p<0.05$) – Table 2. This is because the epoxy resin added to the mixture fills the gaps between the hazelnut shells, and the compressive strength of the hardened epoxy resin (63 MPa) is much higher than the hazelnut shell ratios.

CONCLUSIONS

Insulation materials created from agricultural waste are preferred not only because they help to reduce waste-related environmental pollution, but can also save energy when used for insulation purposes in buildings. In this regard, different studies have been carried out to provide energy-saving insulation materials in buildings and utulize agricultural wastes. Efforts to transform low-temperature, fibrous, non-harmful, low-density agricultural wastes into materials that will save energy in buildings will make an important contribution to the production of insulation materials to be used in the future. At the same time, with the use of these wastes, it will be possible to produce new materials adequate for green buildings.

In this study, potential use of a new insulation material (HSIB) produced from a mixture of hazelnut shell, an agricultural waste that causes environmental problems, and epoxy resin was investigated. As a result of the research, it was determined that the designed building material (HSIB) could not reach the required thermal conductivity coefficient value so as to be defined as an insulation material, but it showed very high insulation properties compared to existing building materials. Similarly, according to the experimental results obtained, it can be said that the insulation material produced could be used for sound insulation as well as heat and sound insulation. For this reason, it can be mentioned that it can be used to improve thermal insulation in buildings and energy savings can be achieved. However, the high water absorption rates of the boards, especially ones with the low amount of epoxy resin, limit their use in building elements exposed to water. It may be recommended to increase the amount of epoxy resin used in the hazelnut shell board, to use it together with insulation materials, or to use it on the interior surfaces of the building in order to counteract this disadvantage.

When evaluated in terms of strength properties, it was seen that as the amount of epoxy resin increased, the strength properties increased. Additionally, unit volume values increased in direct proportion to the amount of epoxy resin. This shows that epoxy resin fills the gaps between hazelnut shells.

As a result, a material (HSIB) with high insulating properties can be produced using ground hazelnut shells, which are an agricultural waste. It has been determined that energy savings can be achieved by increasing the insulation properties of the buildings with this material. It can be said that a value-added building material can be produced from hazelnut shells, which could also prevent the environmental damage caused by hazelnut shells as an agricultural waste.

Author contributions

M.O – conceptualization, data curation, formal analysis, investigation, methodology, project management, resources, spelling, C.B.S – original draft preparation, writing – review and editing, data curation, official analysis.

Conflicts of interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

REFERENCES

Arslan, M.A., Aktaş, M. (2018) 'Evaluation of insulation materials used in construction sector based on heat and sound insulation', *Journal of Polytechnic*, 21(2), 299-320, available: https://doi.org/10.2339/politeknik.407257

ASTM (1994) 'Standard Test Method for Pulse Velocity Through Concrete- ASTM C 597', *Annual Book of ASTM Standard*

ASTM 1990. 'Test Method for Thermal Conductivity of Refractories by Hot Wire- ASTM C 1113-90', *Annual Book of ASTM Standard.*

Al-Homoud, M.S. (2005) 'Performance characteristics and practical applications of common building thermal insulation materials', *Building and Environment*, 40(3), 353-366, available: https://doi.org/10.1016/j.buildenv.2004.05.013

Al-Sallal, K.A. (2003) 'Comparison between polystyrene and fiberglass roof insulation in warm and cold climates', *Renewable Energy*, 28(4), 603-611, available: https://doi.org/10.1016/S0960-1481(02)00065-4

Asdrubali, F. (2016) 'Insulation materials for the building sector: A review and comparative analysis', *Renewable and Sustainable Energy Reviews*, 62(1), 988-1011, available: https://doi.org/10.1016/j.rser.2016.05.045

Ashour, T., Georg, H., Bockisch, F.J. and Wu, W. (2010) 'The influence of natural reinforcement fibres on insulation values of earth plaster for straw bale buildings', *Materials Design*, 31(10), 4676-4685, available: https://doi.org/10.1016/j.matdes.2010.05.026

Barreca, F. and Fichera, C.R. (2013) 'Use of olive stone as an additive in cement lime mortar to improve thermal insulation', *Energy and Buildings,* 62(1), 507-513, available: https://doi.org/10.1016/j.enbuild.2013.03.040

Bars, T. (2021) 'Product Report – Hazelnut - 2021'. *Agricultural Economics and Policy Development Institute Publications*, available: https:// fındık Ürün Raporu 2021-340 TEPGE.pdf (tarimorman.gov.tr)

Bars, T. (2023) 'Product Report – Hazelnut - 2023'. *Agricultural Economics and Policy Development Institute Publıcations*, available: https:// fındık Ürün Raporu 2023-376 TEPGE.pdf (tarimorman.gov.tr)

Belhadj, B., Bederina, M., Montrelay, N., Houessou, J. and Queneudec, M. (2014) 'Effect of substitution of wood shavings by barley straws on the physico-mechanical properties of lightweight sand concrete', *Construction and Building Materials,* 66(1), 247-258, available: https://doi.org/10.1016/j.conbuildmat.2014.05.090

Binici, H., Sevinç, A.H., Eken, M. and Demirhan, C. (2014) 'Corn on the cob added heat insulation material production', Çukurova *University Journal of Faculty Engineering and Architecture*, 29(2), 13-26, available: https://doi.org/10.21605/cukurovaummfd.242831

Brundtland, G.H. (1987) 'Our common future - Call for action', *Environmental Conservation*, 14(4), 291-294, available: https://doi.org/10.1017/S0376892900016805

Can, M.F. (2008) 'Sepiolite/epoxy nanocomposite production and characterization', PhD thesis, Istanbul Technical University, Institute of Science and Technology, Istanbul.

Chikhi, M., Agoudjil, B., Boudenne, A. and Gherabli, A. (2013) 'Experimental investigation of new biocomposite with low costfor thermal insulation', *Energy and Buildings*, 66(1), 267-273, available: https://doi.org/10.1016/j.enbuild.2013.07.019

Cravo, J.C.M., Sartori, D.D., Nakanishi, E.Y., Fiorelli, J., Balieiro, J.C.D. and Dos Santos W.N. (2014) 'Ecological lining of agro industrial waste for poultry houses', *Ciencia Rural*, 44(8), 1466-1471, available: https://doi.org/10.1590/0103-8478cr20120871

Çalışkan Değirmenci, Ö., Aydoğan, İ., Aras, M. and Çerçevik, A.E. (2015) 'Epoxy Usage in Anchors', *Bilecik* Şeyh *Edebali University Journal of Science,* 2(1), 69-74.

Çanakci, H., Demirboğa, R., Karakoç, M. B. and Şirin, O. (2007) 'Thermal conductivity of limestone from Gaziantep (Turkey)', *Building and Environment,* 42(1), 1777-1782, available: http://doi.org/10.1016/j.buildenv.2006.01.011

De Wilde, P. and Van der Voorden, M. (2004) 'Providing computational support for the selection of energy saving building components', *Energy and Buildings*, 36(8), 749-758, available: https://doi.org/10.1016/j.enbuild.2004.01.003

Demir, T. and Beyhan, N. (2000) 'A study on the selection of hazelnuts grown in Samsun', *Turkish Journal of Agriculture and Forestry*, 24(2), 173-183.

Demirbaş, E. (2003) 'Adsorption of cobalt (II) ions from aqueous solution onto activated carbon prepared from hazelnut shells', *Adsorption Science Technology,* 21(10), 951-963, available: https://doi.org/10.1260/02636170360744380

Demirbo'a, R. (2003) 'Influence of mineral admixtures on thermal conductivity and compressive strength of mortar', *Energy and Buildings,* 35(1), 189-192, available: http://doi.org/10.1016/S0378-7788(02)00052-X

Djoudi, A., Khenfer, M.M., Bali, A. and Bouziani, T. (2014) 'Effect of the addition of date palm fibers on thermal properties of plaster concrete: experimental study and modeling', *Journal of Adhesion Science Technology*, 28(20), 2100-2111, https://doi.org/10.1080/01694243.2014.948363

Ergun, M. (1995) 'Computer Statistics Applications in Scientific Researches Spss for Windows', *January Publications, 292,* available: http://doi.org/10.22438/jeb/38/5(SI)/GM

Evon, P., Vandenbossche, V., Pontalier, P. and Rigal L. (2014) 'New thermal insulation fiberboards from cake generated during biorefinery of sunflower whole plant in a twin-screw extruder', *Industrial Crops and Products,* 52(1), 354-362, available: https://doi.org/10.1016/j.indcrop.2013.10.049

Grubbe, K., Haenel, R. and Zoth G. (1983) 'Determination of the vertical component of thermal conductivity by line source methods', *Zentralblatt* für *Geologie und Palaontologie,* 1(1-2), 49-56.

Hoşgün, E.Z. and Bozan, B. (2017) 'Investigation of the effect of low temperature low time alkaline pretreatments on the composition and enzymatic hydrolysis of hazelnut shell', *Journal of Faculty of Engineering and Architecture of Gazi University,* 32(2), 517-529, available: https://doi.org/10.17341/gazimmfd.322177

Karaağaç, İ., Durmus, G., Uluer, O., Aktaş, M. and Tülü, F.A. (2016) 'The approaches to determine of heat transfer coefficient for composite thermal insulation panel', *El-Cezeri Journal of Science and Engineering,* 3(1), 133-142, available: https://doi.org/10.31202/ecjse.67154

Karakoç, T.H., Binyıldız, E. and Turan O. (1999) 'Thermal insulation in buildings and installations', *ODE Technical Publications,* No: G20.34-39, Istanbul.

Khedari, J., Nankongnab, N., Hirunlabh, J. and Teekasap, S. (2003) 'New insulating particleboards from durian and coconut coir', *Building and Environment*, 38(3), 435-441, available: https://doi.org/10.1016/S0360-1323(02)00030-6

Khedari, J., Nankongnab, N., Hirunlabh, J. and Teekasap S. (2004) 'New low-cost insulation particleboards from mixture of durian peel and coconut coir', *Building and Environment,* 39(1), 59-65, available: https://doi.org/10.1016/j.buildenv.2003.08.001

Khedari, J., Suttisonk, B., Pratinthong, N. and Hirunlabh, J. (2001) 'New lightweight composite construction materials with low thermal conductivity', *Cement and Concrete Composites,* 23(1), 65-70, available: https://doi.org/10.1016/S0958-9465(00)00072-X

Korjenic, A., Petranek, V., Zach, J. and Hroudova, J. (2011) 'Development and performance evaluation of natural thermal-insulation materials composed of renewable resources', *Energy and Buildings*, 43(9), 2518-2523, available: https://doi.org/10.1016/j.enbuild.2011.06.012

Kymäläinen, H.R. and Sjöberg, A.M. (2008) 'Flax and hemp fibres as raw materials for thermal insulations', *Building and Environment,* 43(7), 1261-1269, available: https://doi.org/10.1016/j.buildenv.2007.03.006

Lertsutthiwong, P., Khunthon, S., Siralertmukul, K., Noomun, K. and Chandrkrachang S. (2008) 'New insulating particleboards prepared from mixture of solid wastes from tissue paper manufacturing and corn peel', *Bioresource Technology*, 99(11), 4841-4845, available: https://doi.org/10.1016/j.biortech.2007.09.051

Mati-Baouche, N., De Baynast, H., Lebert, A., Sun, S., Lopez-Mingo, C.J.S., Leclaire, P., and Michaud, P. (2014) 'Mechanical, thermal and acoustical characterizations of an insulating bio-based composite made from sunflower stalks particles and chitosan', *Industrial Crops and Products*, 58(1), 244-250, available: https://doi.org/10.1016/j.indcrop.2014.04.022

Ozocak, M. and Sisman, C.B. (2020) 'Usability of hazelnut shell ash as pozzolan in concrete', *Fresenius Environmental Bulletin,* 29(12), 10366-10375.

Ömür, Ö. M. (2023). 'The importance of hazelnuts in turkey and the effect of area-based income support for hazelnuts on yield and its relationship with the production area: Panel data analysis within the scope of selected provinces', *Journal of Black Sea Studies*, 77: 309-329.

Özcan, F. and Akçaözoğlu, K. (2018) 'Determination of thermal conductivity values of air-entrained concretes', *Nigde Omer Halisdemir University Journal of Engineering Sciences,* 7(2), 716-724, available: https://doi.org/10.28948/ngumuh.444752

Panyakaew, S. and Fotios, S. (2011) 'New thermal insulation boards made from coconut husk and bagasse', *Energy and Buildings*, 43(7), 1732-1739, available: https://doi.org/10.1016/j.enbuild.2011.03.015

Papadopoulos, A. M. (2005) 'State of the art in thermal insulation materials and aims for futuredevelopments', *Energy and Buildings*, 37(1), 77-86, available: https://doi.org/10.1016/j.enbuild.2004.05.006

Qi, B., Zang, Q.X., Bannister, M. and Mai, Y.W. (2006) 'Investigation of the mechanical properties of DGEBA-based epoxy resin with nanoclay additives', *Composite Structure,* 75(1-4), 519-519, available: https://doi.org/10.1016/j.compstruct.2006.04.032

Sass, J. H., Stone, C. and Munroe R J. (1984) 'Thermal conductivity determinations on solid rock – a comparison between a steady-state divided-bar apparatus and a commercial transient line-source device', *Journal of Volcanology and Geothermal Research,* 20(1-2), 145-153, available: https://doi.org/ 10.1016/0377-0273(84)90071-4

Saura-Calixto, F., Canellas, J. and Garcia-Raso, V. (1983) 'Contents of detergent-extracted dietary fibers and composition of hulls, sheels, and teguments of almonds (Prunus amygdalus)', *Journal of Agricultural and Food Chemistry*, 31(6), 1255-1259, available: https://doi.org/10.1021/jf00120a027

Schiavoni, S., D'Alessandro F., Bianchi F. and Asdrubali, F. (2016) 'Insulation materials for the building sector: A review and comparative analysis', *Renewable and Sustainable Energy Reviews,* 62(1), 988-1011, available: https://doi.org/10.1016/j.rser.2016.05.045

SPO (2021) '2020 Hazelnut sector report', *Soil Products Office – Turkish,* available: https://www.tmo.gov.tr/Upload/Document/sektorraporlari/findik2020.pdf

Şenkal Sezer, F. (2005) 'Development of thermal insulation in Turkey and exterior wall thermal insulation systems applied in residences', *Uludag University Journal of Faculty of Engineering,* 10(2), 79-85, available: https:// doi:10.17482/uujfe.63488

Temiz, S. (2003) 'Investigation of the effects of environmental factors on the mechanical properties of adhesive joints', PhD Thesis, Atatürk University, Institute of Science and Technology, Erzurum.

TSI (1981) 'Test method for determination the unit weight, water absorption and void ratio in hardened concrete- TS 3624', *Turkish Standards Institution.*

TSI (1999) 'Testing concrete determination of ultrasonic pulse velocity - TS EN 12504-4', *Turkish Standards Institution.*

TSI (2010) 'Tests for mechanical and physical properties of aggregates - Part 2: Methods for the determination of resistance to fragmentation - TS EN 1097-2', *Turkish Standards Institution.*

TSI (2013) 'Thermal insulation rules in buildings - TS 825', *Turkish Standards Institution.*

TSI (2019) 'Testing hardened concrete compressive strength of test specimens - TS EN 12390-3', *Turkish Standards Institution.*

TSI (2012) 'Test for geometrical properties of aggregates - determination of particle size distribution - sieving method - TS EN 933-1', *Turkish Standards Institution*

TSI (2013) 'Thermal insulation rules in buildings - TS 825', *Turkish Standards Institution.*

Thienprasert, A. and Raksaskulwong, M. (1984) 'Heat flow in northern Thailand', *Tectonophysics,* 103(1), 217-233, available: http://doi.org/10.1016/0040-1951(84)90085-4

Toydemir, N., Gürdal, E. and Tanaçan, L. (2000) Material in Building Element Design. *Literature Publications,* 39(1), 313, İstanbul.

Xu, J.Y., Sugawara, R., Widyorini, R., Han, G.P. and Kawai, S. (2004) 'Manufacture and properties of low-density binderless particleboard from kenaf core', *Journal of Wood Science,* 50(1), 62-67, available: https://doi.org/10.1007/s10086-003-0522-1

Zhou, X.Y., Zheng, F., Li, H.G. and Lu, C.L. (2010) 'An environment-friendly thermal insulation material from cotton stalk fibers', *Energy and Buildings,* 42(7), 1070-1074, available: https://doi.org/10.1016/j.enbuild.2010.01.020

Zhou, X.Y., Li, J. and Zhou, D.G. (2004) 'Thermal transfer properties of low density wheat strawboard', *Journal of Nanijing Forestry University*, 47(06), 1-4, available: https://doi.org/10.3969/j.jssn.1000-2006.2004.06.001