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RICE HUSKS AND THEIR POTENTIAL FOR USE IN CONSTRUCTION

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Abstract

The growing global demand for agricultural food products has inevitably led to increased amounts of natural agro-industrial by-products. Derived from agricultural and industrial processes, these by-products have traditionally and conservatively been considered waste, and their management represents significant environmental challenges. Currently, the potential of this type of natural materials to be reused in new products with added value is recognized, thus contributing to the development of the circular economy at international level but also in Romania. Current research trends in the field of sustainable construction emphasize the numerous benefits of using natural materials in the development of green building products. The paper presents a series of experimental laboratory research with the aim of studying the potential of rice husk, a natural agro-industrial by-product resulting from the food industry, to be used in construction.

Key words: *agro-industrial by-products, sustainable development, waste capitalization.*

INTRODUCTION

Globally, rice is a staple food and consumption tends to remain high even during periods of economic turbulence because low-income consumers turn to cost-competitive foods. Global rice production will trend upwards over the next five years, reaching 523.4 million tons in 2025-2026 (International Grains Council Report, 2021).

A natural agro-industrial by-product of rice processing (Figure 1), rice husks are used in constructions in the form of ash, as a pozzolanic filler, in cement-based binders (Xu et al., 2015) as well as for obtaining new composite materials based on natural rubber for the development of supports of vibration isolation (Ubi et al., 2022), of particle boards with various binders (Wilberforce et al., 2022), or as an addition to improve the physicomechanical properties of bricks used as masonry elements (Uderbayev et al., 2022).

The development of new materials that capitalize on natural agro-industrial by-products in the spirit of the circular economy concept requires a better study of their physical, morphological, and microstructural properties so that sustainable, high-performance, and durable products can be obtained (Stoica et al., 2020). Starting from the multidisciplinary knowledge of the natural agro-industrial by-products, the future properties of some innovative materials can be modelled to provide a positive response to various requirements specific to the construction field (Thieblesson et al., 2024).

Figure 1. Rice husks

From a theoretical point of view, the potential of rice husks to be exploited by obtaining construction materials and products is supported by the following aspects:

- the international but also national context, which encourages the study of this type of natural materials to minimize the cost of raw materials but also to create innovative products

with comparable or even superior characteristics to those of traditional products;
- the accessibility at the national level of this sustainable eco-material, a natural by-product of the food industry, considering the predominantly agrarian nature of the Romanian economy and the existence of domestic rice crops;
- the specific properties of rice husks, determined in turn by their compositional and structural characteristics, and implicitly the characteristics of the different types of construction materials in the composition of which the husk was integrated (Park et al., 2003; Chabannes et al., 2014; 2016);
- the high potential of creating new eco-materials/construction products with high added value, which leads to new possible ways of superior valorisation of this agro-industrial by-product, in the context of the Romanian circular economy.

The paper presents a series of experimental laboratory research aimed at studying the potential of the rice husks to be used in construction, in the form of new innovative construction materials and products.

MATERIALS AND METHODS

This experimental research involved multidisciplinary testing of rice husks to determine their potential use in construction materials/products.

Preliminary tests were conducted to characterize rice husks in terms of their thermotechnical properties, fire behaviour, water absorption capacity, and resistance to mold development. These aspects are crucial for designing compositional recipes that incorporate plant products.

The experimental study was carried out using methods specific to each field, as follows:

To determine the thermotechnical characteristics of the rice husk, the Guarded Hot Plate (GHP) method was used, to measure the thermal resistance of the material at different densities, according to SR EN 12667. The GHP method is a steady state transfer technique heat which offers a significant advantage due to its high accuracy. This allows the equivalent thermal conductivity to be measured over the entire thickness of relatively large samples, leading to representative results. In addition, the GHP method is an absolute method that measures thermal conductivity, at an average imposed temperature, without requiring a certified reference material sample.

The process of measuring thermal conductivity for insulating materials involves maintaining a constant and uniform rate of heat transfer, marked as q (in watts per square meter, or W/m^2), and through the material being tested. The measuring area is in the region located near the centre of the test sample, the space where this heat flow is obtained, around the tested area being the marginal guard area.

In a steady-state thermal regime, the heat flux (Q, in watts, W) through the test area (A) is measured. The specific heat transfer intensity is then calculated by dividing the heat flux by the tested area. At the same time, the temperatures (T1 and T2) on the two sides of the test specimen are measured using temperature transducers placed on the surfaces of the equipment in contact with the test specimen.

The thermal resistance R of the test specimen can be calculated using the measured values of these physical parameters. This calculation, according to SR EN 12667, is given in formula (1):

$$R = (T1 - T2) / Q) * A \qquad (1)$$

where:

- R, T1, T2, Q, and A are the parameters previously listed and described.

Instruments based on the GHP method are suitable for determining the thermal resistance and thermal conductivity of both homogeneous and non-homogeneous test specimens, provided that they are flat and plate-shaped. This allows a wide range of materials to be tested for their thermal properties.

Thermal conductivity tests were performed using a Lambdameter EP500e guarded hot plate apparatus. This high-precision instrument provides a measurement error of less than 1.0% in the range λ = 0.010-0.060 W/(m·K), has a thermal conductivity range between 0.003 and 2W/(m·K), and can test samples with thicknesses up to 200 mm, thus allowing a comprehensive analysis of a wide range of materials.

The test protocol strictly adhered to the guidelines described in SR EN 12667, ensuring that the results are consistent, reliable, and comparable to other tests performed according to the same standard.

To prevent external factors from affecting the measurements, the bulk materials were enclosed in a polyurethane frame during testing. This frame was placed in the thermal guard area, thus eliminating the potential influence of the frame on the test results. This ensures that the thermal conductivity values obtained are solely representative of the material under test, providing accurate and reliable data for further analysis and application.

Due to the polyurethane frame, the tests were conducted at three distinct densities, namely 98.20 kg/m^3, 113.60 kg/m^3 and 128.20 kg/m^3 respectively. For each density, measurements were made at three different temperature points: 10°C, 25°C and 40°C. Each specimen exhibited distinct physical characteristics, illustrating how density influences the thermal conductivity of bulk materials.

To determine the fire behavior of rice husks, to demonstrate how it will influence a fire when it will be used to make biocomposites, innovative, ecological construction materials, and preliminary tests were carried out on the fire behavior of the rice husks (Stoica D. et al., 2019). The method of determining the higher calorific value (heat of combustion) was used, according to the provisions of the test method standard SR EN ISO 1716. It should be noted that rice husks, if thrown in the garbage, pollute the environment or can even spontaneously ignite, having the potential to generate fires (Dragne et al., 2019).

To know the contribution of this natural agricultural by-product when subjected to the action of fire, its fire reaction was determined. Reaction to fire is defined as the behavior of a material, which, through its decomposition, feeds the fire to which it is exposed, under specified conditions (Stoica et al., 2019).

As part of this experimental research, as a first step, to evaluate the fire behavior of rice husks, the value of their higher calorific value (heat of combustion) was determined through laboratory tests, following the provisions of the SR EN ISO 1716:2018 test method standard and the provisions of the conditioning standard SR EN 13238:2010.

Higher heat of combustion, also known as higher calorific value, represents the total amount of heat obtained during the complete combustion of a unit mass of fuel, considering also the latent energy of condensation of water vapor produced by the combustion of hydrogen from the fuel.

The determination of the higher heat of combustion was carried out using a calorimeter, designed to measure the heat released during the combustion of a known amount of fuel.

The higher calorific value is expressed in units of energy per unit mass, such as kilojoules per gram (kJ/g) or megajoules per kilogram (MJ/kg). It indicates the energy that can be released during the complete combustion of the fuel.

The standard method used to determine the higher calorific value of a fuel is known as the bomb combustion method or the bomb calorimetry method. This method involves the complete combustion of a known sample of fuel in a bomb calorimeter, and the heat released during combustion is measured and used to calculate the higher heat of combustion. The higher calorific value of rice husks was determined using a British FTT Bomb Calorimeter.

To carry out the determination, a sample of 50 g of rice husks was taken and conditioned until constant weight, for 48 hours before the tests, at a temperature of (23±2)°C and a relative humidity of (50±5)%. Subsequently, three samples of approx. 0.5 g each were taken from the conditioned rice husks.

The water absorption capacity of rice husks, a critical characteristic for formulating compositional recipes with natural products, was determined using the short-term partial immersion method. This method involves calculating the amount of water absorbed by the husk over a 24-hour contact period.

The rice husks were placed in a cylindrical stainless-steel container equipped with a bottom sieve made of inert material. The sieve, featuring an 80 μm mesh diameter, was essential for allowing the husks to be in contact with the water. The initial mass of the rice husks (m_0) was determined by weighing and then the cylindrical container with the husks was partially immersed in a water tank so that the plant material was immersed (10±2) mm below the surface of the water (Figure 2).

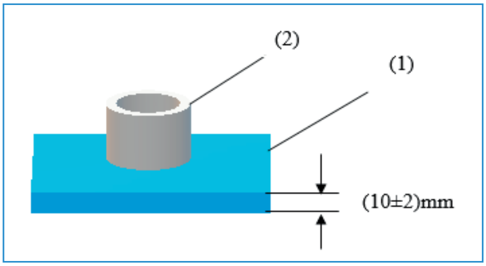

Figure 2. Assembly configuration for determining the water absorption capacity by partial immersion - (1) tank with water; (2) cylindrical stainless-steel container with a sieve

During the determination, the water level was constant. After 24 h, the cylindrical container was removed from the water tank and left to rest for 10±0.5 min on a grid-shaped support, slightly inclined, to allow natural water drainage. The cylindrical container was then weighed to determine the final mass after 24 h of partial immersion, m_{24}. Using equation (2), the short-term (24 h) water absorption by partial immersion corresponding to rice husks, W_p, was calculated, also considering the area (A_p) of the sieve.

$$W_p = \frac{m_{24} - m_0}{A_p} .10^3 \qquad (2)$$

where:

- W_p, m_{24}, m_0 şi A_p are the parameters previously listed and described.

For the primary evaluation of the behaviour of rice husks to the development of molds under the action of high humidity (90±4)% at the normal temperature of (25±2)°C, previously the sample was dried for 72 h at a temperature of (70±2)°C and visually inspected following the development of mold in the product mass and classification according to the standardized criteria mentioned in SR EN 15101-1+A:2019, slightly modified for the current test conditions (Table 1).

A constant amount of plant product of 15 g was used without inoculating the samples with spore suspension. The test assembly was constituted by a desiccator which at the bottom contained a volume of 800 ml of water necessary to create the humidity of (90±4) % inside (Figure 3).

The samples were kept for incubation for 28 days and continuously visually monitored to observe the appearance and degree of mold development.

Table 1. Criteria for classifying mold development

Degree of mold development	Intensity of growth
G0	No visible mold in product mass examined under a reflected light microscope at 50x magnification
G1	Mold growth is visible or barely visible to the naked eye, but clearly visible at 50x magnification
G2	Mold clearly visible to the naked eye

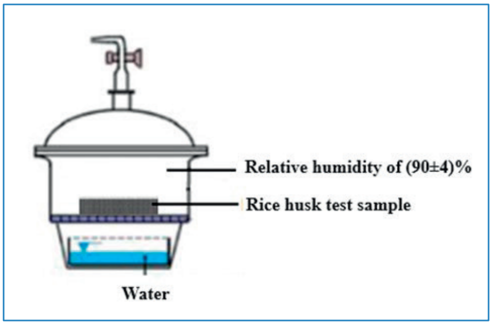

Figure 3. Mold development testing assembly

RESULTS AND DISCUSSIONS

Regarding the thermotechnical characteristics of the rice husks, the obtained experimental results (Figure 4 and Figure 5) indicated the following aspects:

For all samples, thermal conductivity increases with increasing temperature. This is consistent with results obtained on most insulating materials, where thermal conductivity often increases with temperature due to increased molecular motion, leading to greater heat transfer.

The bulk density of the specimens also plays an essential role in determining their thermal properties. Unlike the correlation of the thermal conductivity coefficient of the rice husk with the average temperature of the plates, which appears to be a linear function, the relationship between the rice husk's thermal conductivity and the specimens' average density follows a quadratic function, revealing a local minimum. This local minimum is observed to be around a density of 110 kg/m^3.

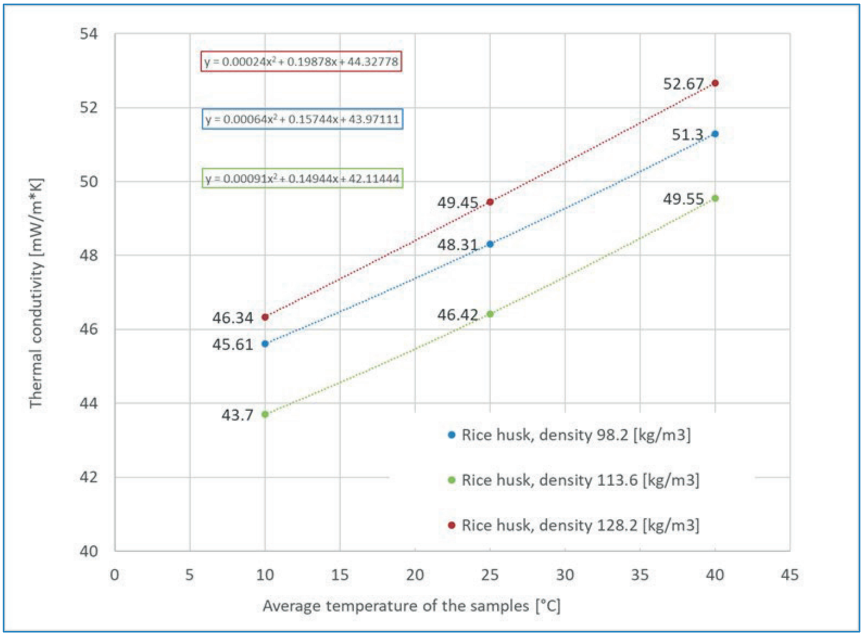

Figure 4. Correlation of the thermal conductivity of the rice husk
with the average temperature of the samples during the tests

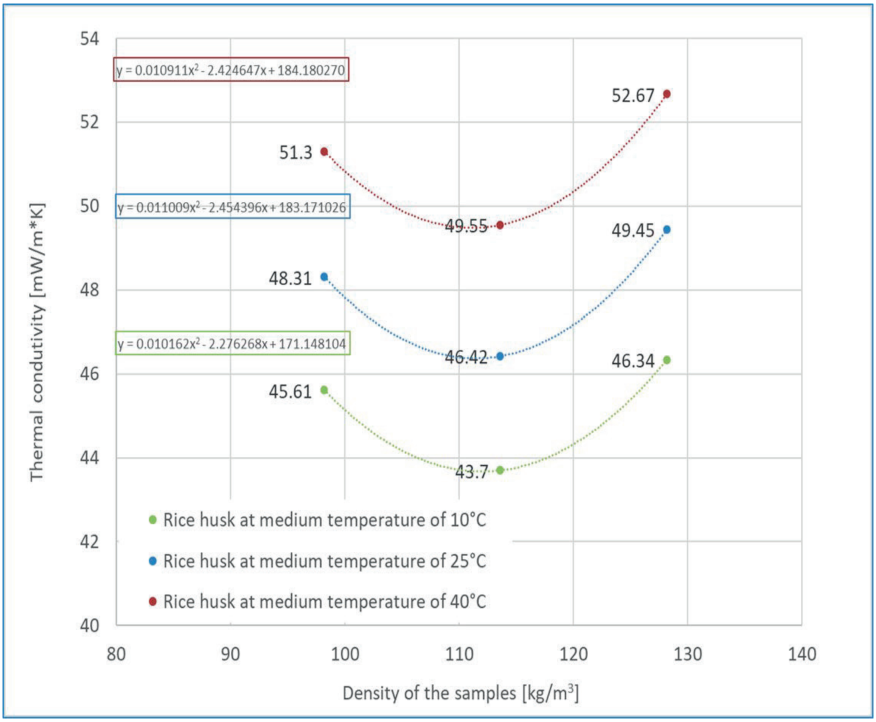

Figure 5. Correlation of the thermal conductivity of the rice husk with the average density of the samples

Using the mathematical relations derived for the interpolation curves, we can determine by derivation and mathematical calculation the exact value of the density for which the lowest thermal conductivity is obtained.

For the average plate temperature of 10°C, this is 112 kg/m^3 and the minimum thermal conductivity value is 43,678 [mW/m*K] or 0.043678 [W/m*K], comparable to that of some synthetic heat-insulating materials.

These research results provide an adequate understanding of how the thermal properties of rice husk-based materials respond to changes in temperature and density.

The trends identified here, particularly the positive correlation between temperature and thermal conductivity, are significant considerations in determining the appropriate use of these materials in insulation applications. However, further studies would be beneficial to deepen the interaction of these factors as well as other factors not included in this data set, such as moisture content, to gain a more comprehensive understanding of the behavior of this material under different conditions.

The results obtained after carrying out tests to determine the higher calorific value, to determine the fire behavior of rice husks, according to the provisions of the test method standard SR EN ISO 1716:2018 (Table 2), indicated a superior value of the calorific value /heat of combustion, comparable to that of wood or coal.

Table 2. Results obtained on the determination of higher calorific value/heat of combustion for rice husks

Type of natural agricultural by-product	Equivalent in water, E [J/K]	Superior calorific value, QPCS [MJ/kg]
Rice husks	10137.00	15.34

As previously stated, the calorific value of a product shows the amount of energy that the product can release when completely burned or oxidized and can be a useful indicator in evaluating its potential for use in various applications, including building materials. The higher the calorific value, the more energy the product contains, being likely to fall into a lower, weaker fire reaction class.

Considering the result obtained, relatively high value, it is advisable that, from the point of view of reaction to fire, rice husks are used in the design of new materials natural, sustainable, and ecological biocomposites, such as fire-retardant boards or insulating materials for fire protection (Bode et al., 2023).

The experimental result obtained regarding the capacity of rice husks to absorb water (Table 3), was obtained using equation (2), which was used to calculate the short-term (24 h) absorption of water through partial immersion corresponding to the husks.

Table 3. Water absorption value of rice husks determined by short-term partial immersion

Sieve diameter, D [mm]	Area, A_p [mm^2]	Initial mass, m_0 [g]	Mass after 24 h of partial immersion, m_{24} [g]	Short-term water absorption by partial immersion, W_P [kg/m^2]
190	28.339	134.45	194.99	2.14

The laboratory test carried out on rice husks regarding short-term water absorption revealed a result that slightly exceeds the water absorption value recorded for a synthetic polymer product, namely polyethylene foam (Figure 6), out of which result a material with sound-absorbing properties, foam tested under similar conditions and taken as a reference level (Chiojdoiu et al., 2023).

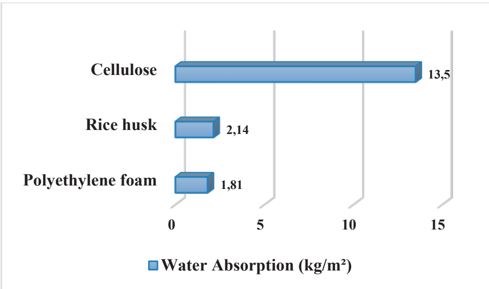

Figure 6. Short-term water absorption by partial immersion for different types of materials

The two values of water absorption are presented in comparison with the corresponding value related to cellulose, a comparison that emphasizes even better the advantage of using rice husks from this point of view in the creation of innovative eco-materials intended for use in construction.

Regarding the resistance of rice husks to the development of molds, at the end of the 28-day incubation period, in addition to visual observations, the samples were examined under a reflected light microscope at a magnification of 50x and classified based on the specified criteria (Table 1).

On visual examination and on that using the reflected light microscope, at a magnification of 50x, the husks did not show mold in the product mass after 1 day of incubation and after 7 days of incubation, respectively, being classified for these time intervals as having degree 0 mold development (G0). At the end of the 28 days, the rice husks sample presented the appearance of mold visible to the naked eye, spread throughout the plant mass subjected to the test, being included in the 2nd degree of mold development (G2).

As a result, it follows that to develop new building materials incorporating rice husks it is necessary to pre-treat them with anti-mold products so that this inconvenience can be completely eliminated so as not to jeopardize the integrity of the future projected material.

CONCLUSIONS

Internationally, researchers are exploring various technologies and processes to valorize natural agro-industrial by-products, including the use of rice husks, with many processes still in the research and development stage.

The research carried out regarding the study and realization of biocomposite products obtained by the valorization of rice husks, products that can be used in construction, demonstrates worldwide the interest of researchers to create, study, and promote such construction materials/products, having properties comparable to those of materials/products made from synthetic raw materials.

At the national level, due to the predominantly agrarian character of the Romanian economy, the valorization of rice husks represents an opportunity to address the environmental challenges raised by this type of by-product, contributing both to the sustainable development of the built environment and to the consolidation of the circular economy.

Due to the experimental results of the determinations carried out in this research, it is considered that, despite the lack of resistance to the development of molds, the potential of rice husks to be used in construction, through the integration of innovative materials, is reconfirmed as a possibility to contribute to the sustainable development of the built environment.

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