Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XV, 2026
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

PHYSICAL AND MECHANICAL CHARACTERISTIC ASPECTS FOR CLADDING PRODUCTS BASED ON RICE HUSKS AND HEMP STALKS

Irina POPA[1], Vasilica VASILE[1], Claudiu-Sorin DRAGOMIR[1, 2], Cristian GRIGORAȘENCO[1]

[1]National Institute for Building Research, Town Planning and Sustainable Territorial Development "URBAN - INCERC", 266 Pantelimon Road, District 2, Bucharest, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, Bucharest, Romania

Corresponding author email: irinapopa2006@yahoo.com

Abstract

Natural agro-industrial by-products and the circular economy concept are closely interconnected, both being essential for promoting sustainability in various representative fields of the economy, such as agriculture, the food industry, the construction industry, etc. The establishment of circular practices in the agro-industrial and construction sectors leads to the minimization of deposits of such materials/natural waste, optimizes their use by increasing their value, and simultaneously creates economic, environmental and social benefits. The paper presents aspects of the experimental research carried out with the aim of the superior valorization of two local agro-industrial by-products, namely rice husks and hemp stalks, by obtaining cladding products usable in construction. It is recognized that due to their compositional and structural particularities, the two natural materials, integrated in different types of construction materials, give them mechanical resistance, thermal insulation properties and acoustic performance. The products resulting from this research were studied from physical and mechanical point of view, considering that additional, multi-criteria tests are necessary, to gain a complete evaluation regarding the field of use in constructions of this type of innovative products.

Key words*: agro-industrial by-products, circular economy, construction, sustainability, waste.*

INTRODUCTION

Currently, humanity is faced with a complex set of problems that are mutually interrelated. On the one hand, construction industry is an important consumer of energy and a major source of waste and greenhouse gas emissions (Cintura et al., 2021). Along with these, the growth of the world population and, implicitly, the necessary built stock, together with the aggressive impact of the conventional building materials industry through air, soil and water pollution, represent current problems that require clear intervention measures (Maraveas, 2020). At a global level, a wide range of directions for the valorization of recyclable materials has been identified, in the form of different types of construction materials/ products. In this regard, examples can be given ranging from the use of rice husk ash as an additional material in concrete production, contributing to improving the strength and durability of concrete (Kumar et al., 2013), the use of biological waste specific to the Euro-Mediterranean area, to obtain construction products and implicitly solving some associated challenges (Cintura et al., 2021), to the development of innovative asphalt mixture recipes, by incorporating different recyclable materials, in order to improve the lifespan of road structures (Ionescu & Dobre, 2025).

On the other hand, as a result of the increased demand for food, the agricultural sector together with the processing industries generate significant quantities of vegetable waste and natural agro-industrial by-products which, unused and improperly stored, also contribute to environmental pollution (Maraveas, 2020; Capanoglu et al., 2022; Yaashikaa et al., 2022; Ufitikirezi et al., 2024; Carrillo-Rodriguez et al., 2025). In this context, it is increasingly necessary to identify ecological approaches for the construction industry, the application of circular economy principles demonstrating that the productive use of agro-industrial waste can constitute an efficient and sustainable solution (Carrillo-Rodriguez et al., 2025). The circular economy contributes to reducing environmental

pollution by minimizing generated waste, optimizing its use through viable processes, and establishing interconnected circular practices between the agri-food and construction sectors. By transforming natural waste into raw materials and creating alternative materials, at much affordable costs (Maraveas, 2020), mainly of organic origin and from recyclable natural materials (Gołębiewski et al., 2025), the circular economy promotes the conservation of the economic value of products and contributes to increasing the added value of the resulting product (Coelho Vianna et al., 2024). The purpose of this experimental research is to find a new possibility of superior utilization in construction for two natural agro-industrial by-products (S.A.N.), namely rice husk and industrial hemp stalks, by obtaining innovative cladding products.

Specialized literature confirms researchers' concern for the exploitation of these S.A.Ns, in various types of construction products.

For exemple, rice husks can be used in plasters and agglomerated composite boards, products characterized by thermal or acoustic insulation properties (Revelo-Cuarán et al., 2022; Marin-Calvo et al., 2023; Milawarni et al., 2023; Pradhan et al., 2024; Wan et al., 2024), in cement blocks as a partial replacement of sand or in fire clay bricks, in form of rice husk ash (Maraveas, 2020).

In turn, hemp stalks are integrated into numerous types of building materials, hemp-lime composites with pro-ecological characteristics (Gołębiewski, 2017). The role of hemp in improving thermal insulation properties is recognized, having one of the lowest thermal conductivity coefficients among commonly studied plant aggregates (Gołębiewski, 2025), while also contributing to the compressive strength and humidity regulation of the materials in which it is integrated. One of the best-known hemp-based construction materials is hemp concrete, obtained by mixing hemp pulp with a lime-based binder. Having good thermal insulation, significant breathability, hygroscopicity and a reduced carbon footprint, high permeability to water vapor, fire resistance, biodegradation, good acoustic properties, it can be used for roofs and floors, or for insulating walls on their exterior side (Gołębiewski, 2017; Demir & Doğan, 2020; Yadav & Saini, 2022; Gołębiewski, 2025). Hemp can also be used to obtain products such as: particleboard and fiberboard, by mixing hemp pulp with other lignocellulosic materials and binders, boards usable as floor and wall panels, as well as biocomposite materials, by combining hemp pulp with a matrix of synthetic or natural polymers, resulting in floors, cladding elements and interior finishes (Cigasova et al., 2015; Dhakal & Zhang, 2015; Requile et al., 2019; Maraveas, 2020).

MATERIALS AND METHODS

Based on the documentation carried out on obtaining cladding products by integrating plant waste, a series of materials were selected to design products of this type, both in ecological and hybrid variants. Both types of recipes integrated rice husks (Figure 1), hemp stalks (hurd) chopped at lengths between 1-5 cm (Figure 2) or mixtures thereof, but different in the nature of the binders.



Figure 1. General appearance of rice husks



Figure 2. General appearance of chopped hemp stalks

In this approach, the eco-recipes had either a natural binder of plant origin, obtained from a mixture of corn starch, hydrated lime and water, or a natural binder of animal origin, based on bone glue (denoted COS). The hybrid recipes had a binder resulting from a mixture of COS

and a synthetic adhesive, based on polyvinyl acetate (denoted AD1) or polyurethane (denoted AD2), the last two materials having the role of improving the cohesion of the cladding product. All recipes have been designed to obtain organic products or products with organic characteristics, from a compositional point of view, with high cohesion and hardness. Thus realized, the recipes allow the comparative study of the influence that the different compositional factors have on the mechanical characteristics of the obtained products. The influencing factors studied were the following: type of binder (natural vs. hybrid binder, respectively its synthetic component); type of the S.A.N. integrated in the product (rice husks vs. rice husks+hurd vs. hurd); presence of the adhesive; type of adhesive (polyvinyl acetate vs. polyurethane). The cladding products were obtained by casting the biomaterials in a steel mold and applying an external pressure, using a press, to reduce excess moisture in the plate mass. The mould was designed and made for this purpose, with dimensions of 270 x 270 x 25 mm. The methodology for obtaining the cladding products consisted of the following sequence of main steps: Preparation of raw materials and binders simultaneously with heating the steel mold in the oven at 70°C, for aprox. 4 hours → Mixing the components according to the recipe and homogenizing them → Pouring the resulting biomaterial into the steel mold → Closing the mold with its lid → Placing the mold + biomaterial assembly in the press and applying an exterior force to it → Demoulding the sample from the mold → Natural drying of the obtained plate, in laboratory conditions (temperature of 23±2°C şi relative air humidity of 50% ± 10%). Regarding this work protocol, the following additions are necessary to be outlined: a. The S.A.N were dried in the oven at 70°C, for approx. 4 hours; b. While the preparation of the vegetable binder consisted only in mixing and homogenizing hydrated lime and corn starch with water, in the case of the COS binder, this was obtained by soaking the granules in water (mixing ratio 1:1 in mass units) for approx. 12 hours, then by heating the obtained gel in a Bain-Marie, up to a temperature of 50-70°C, resulting the bone glue in the colloidal phase; c. There was a slow and constant application of a force to the mold. The maximum value of the applied force varied, on the one hand depending on the moment when the binding liquid phase started to emerge from the mold and, on the other hand, on the values of the external force applied, in order not to affect the integrity of the mold under load. This thermoforming protocol proved to be functional, as the obtained plates showed stability and cohesion between the constituent elements, but required advanced drying. As a result, the plates were weighed every 24 hours, so that the condition of complete drying to constant mass could be reached. Depending on the thickness of the cladding products, drying of the plates continued for about 10 days, after which the cladding products were placed in a vertical position and were normaly dried, in laboratory conditions (temperature of 23±2°C şi relative air humidity of 50% ± 10%), for another about 20 days.

Based on considerations regarding the workability of the biomaterial, as well as the compact aspect of the material both after demolding and at the end of the drying period, four vegetable - bound, six hybrid - bound and three COS - bound cladding products were obtained and then studied by means of their main mechanical characteristics. From the point of view of the vegetable component: binder mixing ratios, compositional benchmarks of the obtained cladding products are presented in Table 1.

Table 1. Compositional benchmarks of the biomaterials obtained by integrating rice husks and hemp stalks

Biomaterial/ Cladding product notation	Binder	S.A.N : binder mixing ratios (mass units)	Vegetable components
C4-1	Vegetable	3:25	P[1]
C6-1	Vegetable	20:70	P, H[2], P=H
C7-1	Vegetable	20:70	P, H, P=H
C8-1	Vegetable	20:70	P, H, P=H
PMI′	COS, AD1	1:3.74	P
PMI″	COS, AD2	1:3.77	P
PMIII′	COS	1:5.75	P, H, P=H
PMIII‴	COS	1:5.75	P, H, P<H
PMIII‴bis	COS	1:3.50	P, H, P<H
PMIV′	COS, AD1	1:4,30	P, H, P<H
PMIV″	COS, AD2	1:3.50	P, H, P<H
PMV′	COS, AD1	1:4.03	H
PMV″	COS, AD2	1:4.20	H

[1]P=Husk rice.
[2]H=Hurd (Choped hemp stalks).

After drying, the general appearance of the obtained cladding products was different

depending on the incorporated S.A.N. but also on the binder (Figures 3, 4 and 5).



Figure 3. Examples of the general aspect of vegetable-bound cladding products based on rice husks (left), and on a mix of rice husks and choped hemp stalks (right)



Figure 4. Example of the general aspect of COS-bound cladding products based on rice husks

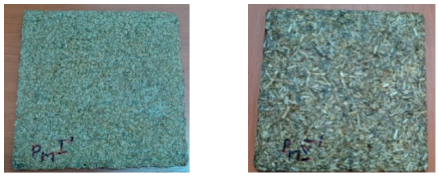


Figure 5. Examples of the general aspect of hybrid - bound cladding products based on rice husks (left), and on a mix of rice husks and choped hemp stalks (right)

The general appearance of the cladding products illustrates their cohesive, compact character.
In order to highlight the significant differences among all the materials with different compositions developed and presented in this research, a statistical analysis was applied, using a one-way analysis of variance (one-way ANOVA). The software used to perform the statistical analysis was Microsoft Excel.

RESULTS AND DISCUSSIONS

The determination of physical and mechanical characteristics was performed on both eco- and hybrid-recipes cladding products. Each plate was measured to establish dimensional compliance, the nominal thickness and side length. After the end of the drying period of the cladding products, the measured values of the sides were between 255 mm (PMIII‴) and 267 mm (C4-1), and the average thickness values, between 8.23 mm (PMIII′) and 22.84 mm (PMV″). The modulus of elasticity in bending was determined by applying a constant speed load to the middle of the sample placed on two supports. For the calculation of the value, the slope of the rectilinear area of the load-deformation curve was used.
The bending load-deflection diagrams have a comparable appearance for all types of recipes, with a linear upward evolution on the first portion of the representation, followed by a threshold value, the maximum load, corresponding to the resistance of the base material.
Subsequently, the material failure occurred and the curve becomes descending, some examples being illustrated in Figure 6, for the two test pieces of C4-1 and PMIII‴ clading product. The results regarding the flexural strength and modulus of elasticity for all the obtained cladding products are graphically represented in the Figures 7 and 8.

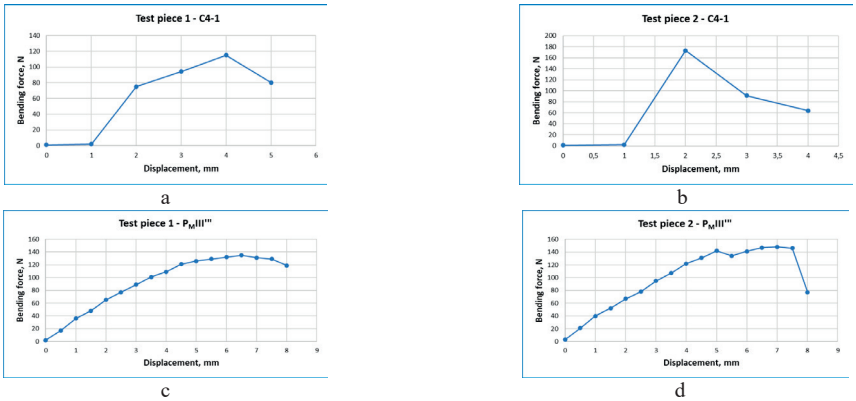


Figure 6. Load-deformation curves. Specific examples for C4-1 (a, b) and PMIII‴ (c, d) cladding product

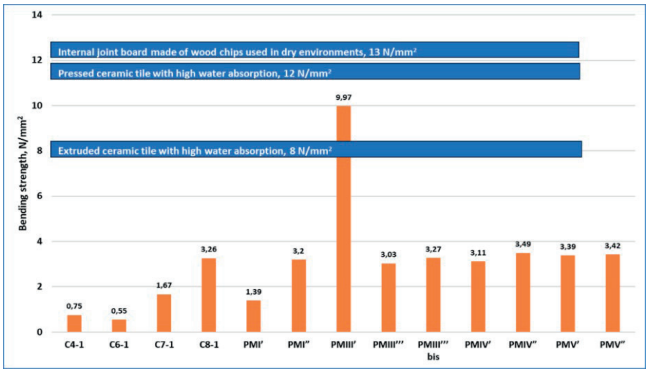


Figure 7. Bending strength of rice husk and hemp stalks based cladding products

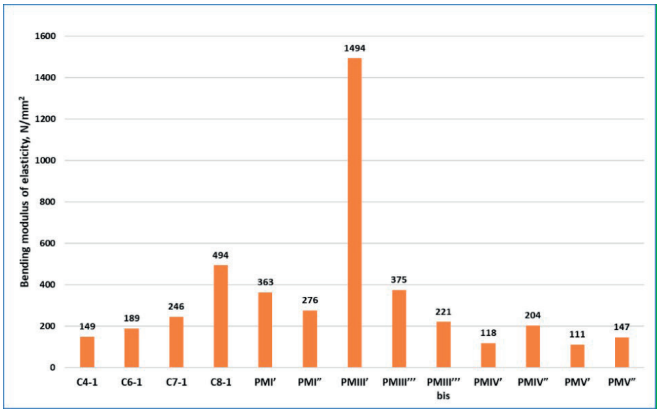


Figure 8. Bending modulus of elasticity for rice husk and hemp stalks based cladding products

Regarding eco - cladding products, the highest value for flexural strength was obtained for C8-1, of 3.26 N/mm^2 with a flexural modulus of elasticity of 494 N/mm^2 at an average board thickness of 8.30 mm. This value is comparable to that of PMI″, average plate thickness 12.68 mm (flexural strength 1.39 N/mm^2, flexural modulus 363 N/mm^2), of PMIII‴, average plate thickness 9.28 mm (flexural strength 3.03 N/mm^2, flexural modulus 375 N/mm^2) and of PMIII‴bis, average plate thickness 16.37 mm (flexural strength 3.27 N/mm^2, flexural modulus 221 N/mm^2), which contain COS with or without synthetic products for binding the vegetable fraction. This is why, the C8-1 recipe consisting of rice husks, hurd, lime and corn starch represents a compositional variant to be taken into account for further optimization.

The best bending strength was recorded for PMIII′, with a value of 9.97 N/mm^2 and a bending modulus of elasticity of 1494 N/mm^2, for an average thickness of 6.86 mm, the product having an eco-recipe based on rice husks, chopped hemp stalks and COS.The bending load-deflection diagrams have a comparable appearance for all types of recipes, the maximum load, corresponding to the strength of each material, reaching the value of 1110 N. The strength of PMIII' tends to reach the value of bending strength of boards based on wood chips intended for use in dry environments and may represent a premise for future compositional development.

From the analysis of these obtained results, the following aspects can be highlighted:

The best results from a mechanical point of view were obtained in the case of cladding products with eco-recipes having bone glue as a binder and those with hybrid recipes, especially with polyurethane adhesive.

Also noteworthy were the products with mixed vegetable content, regardless of the type of

binder, and in the case of the products with eco-recipes, the C8-1 board, with the highest corn starch content.

It is considered useful to highlight that this research is characterized by a certain limitation regarding the possibility of interpreting the obtained experimental results. The limitation is explained by the fact that the research is still in development, with the aim of identifying the field in which the obtained products could be classified, and subsequently studying the possibilities of their improvement. In this context, it is specified that the methodology applied for determining the bending strength and the bending modulus of elasticity was similar to that of SR EN 310, but the tests were performed on a small number of samples, the graphic representations of the mentioned characteristics being made based on the obtained average values.

To assess whether the flexural strength differs between the 13 cladding products (configurations), a one-way ANOVA analysis was applied, which revealed significant differences between groups ($F(12,13) = 8.84$; $p = 0.00021$), with a very large effect of configuration on flexural strength ($\eta^2 = 0.89$). The same analysis revealed significant differences in the flexural modulus of elasticity between the 13 cladding products ($F(12,13) = 7.99$; $p = 0.00035$), with the configuration explaining approximately 88% of the variation in the values ($\eta^2 = 0.88$). The value of the F statistic indicates greater variability between the 13 groups (recipes) of cladding products and less within the same group of specimens.

CONCLUSIONS

Rice husks and industrial hemp constitute a category of S.A.N. with a high potential for valorization in the form of various types of construction products. Seven cladding products with natural binders and six with hybrid binders were studied in terms of mechanical characteristics, representing the first stage in evaluating their potential for use in construction. From a compositional point of view, the cladding products that had the mixed natural binder, of corn starch and hydrated lime had a more cohesive structure than those with a single vegetable binder, starch or lime.

The cladding products have mechanical characteristics higher than those of extruded ceramic tiles with high water absorption and relatively close to those of pressed ceramic tiles with high water absorption, characteristics that can still be improved.

Based on the experimental results obtained up to this stage of research on innovative cladding products containing rice husks and/or chopped industrial hemp stalks, it is considered that additional tests are necessary in order to achieve a more complete assessment of their potential for use in construction.

ACKNOWLEDGEMENTS

This research work was carried out with the support of Ministry of Research, Innovation and Digitalization and also financed from Project PN 23 35 02 01 “Innovation and Digitalization Synergies in the Design of Eco-Materials and Multifunctional Products for Sustainable Construction, with Impact on the Environment and the Circular Economy”.

REFERENCES

Capanoglu, E., Nemli, E., & Tomas-Barberan, F. (2022). Novel Approaches in the Valorization of AgriculturalWastes and Their Applications. *Journal of Agricultural and Food Chemistry, 70*, 6787–6804.

Carrillo-Rodriguez, L.A., Cajigas Romero, M., & Galindo Larrahondo, J.A. (2025). The use of agro-industrial waste towards a sustainable circular economy: A systematic review. *Detritus, 31*, 45.

Cigasova, J., Stevulova, N., Schwarzova, I., Sicakova, A., & Junak, J. (2015). Application of hemp hurds in the preparation of biocomposites. *IOP Conference Series: Materials Science and Engineering, 96, 012023.* IOP Publishing.

Cintura, E., Nunes, L., Esteves, B., & Faria, P. (2021). Agro-industrial wastes as building insulation materials: A review and challenges for Euro-Mediterranean countries. *Industrial Crops and Products*, *171*, 113833.

Coelho Vianna, L.M., de Oliveira, L., & Muhl, D.D. (2024). Waste valorization in agribusiness value chains. *Waste Management Bulletin Journal, 1*, 195–204.

Demir, İ., & Doğan, C. (2020). Physical and mechanical properties of hempcrete. *The Open Waste Management Journal*, *13*(1), 26–34.

Dhakal, H. N., & Zhang, Z. (2015). The use of hemp fibres as reinforcements in composites. *Biofiber Reinforcements in Composite Materials*, 86–101.

Gołębiewski, M. (2017). Hemp-Lime Composites in Architectural Design. *Kwartalnik Naukowy Uczelni Vistula, 4(54),* 162–171.

Gołębiewski, M., Pietruszka, B., Piątkiewicz, W., Kubiś, M., & Oleksiienko, O. (2025). Compressive Strength, Thermal Conductivity, Vapor Permeability and Specific Heat of Hemp-Lime Composites Varying in Density for Wall, Roof and Floor Applications. *Materials*, *18*, 4958.

Ionescu, N.-A., & Dobre, D. (2025). Behavior of asphalt mixtures manufactured with recycled materials and their in situ performance level. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 14*, 252–259.

Kumar, S., Sangwan, P., Dhankhar, R.M.V., & Bidra, S. (2013). Utilization of rice husk and their ash: A review. *Research Journal of Chemistry and Environment*, *1*, 126–129.

Maraveas, C. (2020). Production of Sustainable Construction Materials Using Agro-Wastes, *Materials*, *13*, 262.

Marin-Calvo, N., González-Serrud, S., & James-Rivas, A. (2023). Thermal insulation material produced from recycled materials for building applications: Cellulose and rice husk-based material. *Frontiers in Built Environment, 9,* 1271317.

Milawarni, M., Aprilia, S., Idris, N., Elfiana, E., Yassir, Y., Asnawi, Y., Suryati, S., Novi Quintena, R., Syarif, J., & Juhan N. (2023). Analysis of Physical and Mechanical Properties of Rice Husk-based Particle Board, *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *31*(3): 40–46.

Pradhan, S.; Entsminger, E.; Mohammadabadi, M.; Seale, D., & Ragon, K. (2024). Evaluation of rice husk composite boards prepared using different adhesives and processing methods. *BioResources*, *19,* 595–604.

Requile, S., Le Duigou, A., Bourmaud, A., & Baley, C. (2019). Hygroscopic and Mechanical Properties of Hemp Fibre Reinforced Biocomposites. *Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials*, *29*(4), 253–260.

Revelo-Cuaran, E.A., Nieves-Pimiento, N., & Toledo-Bueno, C.A. (2022). Homogenization Analysis in Particle Boards with Rice Husk Reinforcement. *Tecnura*, *26*, 59–79.

SR EN 310 – Wood-based panels. Determination of modulus of elasticity in bending and bending strength, 1996.

Ufitikirezi, J. d. D. M., Filip, M., Ghorbani, M., Zoubek, T., Olšan, P., Bumbalek, R., Strob, M., Bartoš, P., Umurungi, S.N., Murindangabo, Y.T., Heřmánek, A., Tupý, O., Havelka, Z., Stehlík, R., Černý, P., & Smutný, L. (2024). Agricultural Waste Valorization: Exploring Environmentally Friendly Approaches to Bioenergy Conversion. *Sustainability*, *16*, 3617.

Wan, D., Tian, C., Cai, Q., & Zhang, X. (2024). Investigating the characteristics and thermal performance of plaster composites enhanced with paddy husk for sustainable Residential construction. *Case Studies in Thermal Engineering*, *60*, 1–8.

Yaashikaa, P.R., Senthil Kumar, P., & Varjani, S. (2022). Valorization of agro-industrial wastes for biorefinery process and circular bioeconomy: A critical review. *Bioresource Technology*, 343, 126126.

Yadav, M., & Saini, A. (2022). Opportunities & challenges of hempcrete as a building material for construction: An overview, Materials Today: *Proceedings, 65*(2), 2021–2028.