PRELIMINARY RESEARCH REGARDING THE CREATION OF A CATEGORY OF COMPOSITE MATERIAL BASED ON A MUD MATRIX AND AGRICULTURAL WASTE AS FILLER MATERIALS

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CERCETĂRI PRELIMINARE PRIVIND REALIZAREA UNUI MATERIAL COMPOZIT, BAZAT PE MATRICE DE NĂMOL ȘI DEȘEURI AGRICOLE, CA MATERIALE DE UMPLUTURĂ

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ABSTRACT

The article presents the results of preliminary experiments necessary for the foundation of an experimental method that ensures the design and manufacturing technology for a category of composite materials with a mud matrix and agricultural waste insertion. The resources and physico-chemical properties of the mud matrix as well as the resources and physical properties of potential agricultural waste constituents of the insertion in the composite material are presented. The technological variant for the manufacture of the finished product is also presented, consisting of a compression system of the composite mixture in a paste state until solidification with moisture removal (dehydration). From a large number of parameters characterizing the experimental system, few have been varied (insertion concentration in the material, height of the raw material column in the press, raw material density, pressing force), while the quality parameters of the process have only been considered for the capacity of dehydration and material densification. The statistical analysis of the results shows that for the capacity of dehydration and densification, the main input parameters that influence are the initial moisture and initial volume of raw material. Results are obtained that allow the development of a mathematical model for the technological process of manufacturing the composite material. The purpose of the research described in this article is to determine the feasibility and feasibility conditions of the material in its possible variations. This means identifying the insertion concentration and moisture intervals of the material before extrusion, possible. The upper and lower limits of these parameters are sought, so that the material exiting the die does not immediately, or over time, disintegrate, and at the same time, the extrusion process is possible with a reasonable energy consumption.

REZUMAT

Articolul prezintă rezultatele experimentelor preliminare necesare fundamentării unei metode experimentale care să asigure concepția și tehnologia de fabricație pentru o categorie de materiale compozite cu matrice de nămol și inserție de deșeuri agricole. Se prezintă resursele și proprietățile fizico-chimice ale matricii de nămol precum și resursele și proprietățile fizice ale deșeurilor agricole potențial constituente ale inserției în materialul compozit. Se prezintă și varianta tehnologică de fabricare a produsului finit constând într-un sistem de comprimare a amestecului compozit în stare de pastă până la solidificare cu eliminarea umidității (deshidratare). Dintr-un număr mare de parametri care caracterizează sistemul experimental, au fost variați puțini (concentrație de inserție în material, înălțimea coloanei de materie primă în presă, densitatea materiei prime, forța de presare) iar ca parametri de calitate ai procesului, deocamdată au fost considerați numai capacitatea de deshidratare și densificarea materialului. Analiza statistică a rezultatelor arată că pentru capacitatea de deshidratare și densificare, principalii parametri de intrare care influențează sunt umiditatea inițială și volumul inițial de materie primă. Se obțin rezultate care permit obținerea unui model matematic pentru procesul tehnologic de fabricare a materialului compozit. Scopul cercetărilor descrise în acest articol este stabilirea fezabilității și condițiilor de fezabilitate ale materialului in variantele posibile. Aceasta înseamnă identificarea intervalelor concentrației de inserție și umidității materialului înainte de extrudare, posibile. Se caută limitele superioară și inferioară ale acestor parametri, astfel încât materialul ieșit din matriță să nu se destrame imediat sau în timp și în același timp procesul de extruziune să fie posibil cu un consum rezonabil de energie.

INTRODUCTION

With the massive technological advancement of the industry, population growth, and climate change, a serious problem arises, namely the decrease of water resources due to pollution. Quick solutions are being sought to solve this problem.

As a result of water purification, a significant amount of sludge is produced, which contains inert and polluting substances, and its processing and valorisation is costly.

According to *(IRS SR 12702, 1997)*, sludge is a complex colloidal system resulting from the treatment of surface waters or the purification of wastewater, with a heterogeneous composition, containing water and suspended, colloidal, mineral, and organic particles, in which products of metabolic activities and/or raw materials, intermediate products, and finished products of industrial activities are incorporated.

One of the methods of valorising sludge is its use along with other filler materials to obtain composite materials to be used in different fields. The use of composite materials made from waste has the primary role of protecting the environment and increasing awareness of sustainability issues, which is very important. Composite materials can be self-recyclable and have high hardness, low density, good tensile strength, and low energy consumption.

To obtain bricks, a mixture of 45% cement and 55% sludge is centrifuged for 15 minutes until a homogeneous paste is obtained. This paste is poured into moulds and left to dry for 24 hours. To increase its strength, the brick is left in the open air for 3-4 days after being removed from the mould (*Pricop F. et al., 2017; Pop M., 2016*).

Another use of composite materials based on waste such as flakes, wood powder, and recycled plastic is for insulation panels, curb stones, frames, and plates (http://petbiocomp.ee.tuiasi.ro).

In a doctoral thesis by *Corbu O. in 2011*, a type of high-performance concrete made with waste glass aggregates was studied, followed by waste concrete and glass. In Brazil, briquettes were produced using dry sludge and vegetable oil, resulting in a calorific potential of 12.94 MJ/kg, slightly lower than coal but with a higher density (*Rocha S. et al., 2022*).

Dry sludge from wastewater treatment can also be used in brick production, mixed with clay in proportions of 0-40% of the brick's weight. The brick's surface is uneven, and its porosity is high, with specific weight and compressive strength decreasing as the sludge content increases (Matar M., 2008). Another type of brick results from mixing sludge with clay and shale, called bio-brick. It has the appearance and smell of ordinary bricks (*Allemanand J. E., 1984; Matar M., 2008*).

A state-of-the-art review on coir fibre-reinforced biocomposites is given in *(Hasan K.M.F.et al., 2021).* The preliminary feasibility analysis of braided tubular composites composed of natural fibres is another option for capitalizing on natural fibres, presented in (*Bruni-Bossio B., 2018).* Another variant of valorisation of natural materials in composites is that of mycelium composite construction materials from fungal biorefineries. A critical look at this type of materials is presented in *(Mautner at al., 2020).* Important concerns in the same direction can be found in *(Khalid M.Y., et al. 2021).*

Sludge can also be used in the production of ceramics and glass. Sludge ash contains silicates, the basic raw material in ceramics. Sludge ash is a fine powder that mixes easily with other components of ceramic paste. In other applications, sludge ash is transformed into a glass-like material (*Matar M., 2008; Șerbănoiu A., 2019*).

This article outlines the structure and manufacturing technology of the composite material with a sludge matrix and agricultural waste insertion, with the aim of formulating a systematic working technology that includes input, control (adjustment), and output parameters (including process quality parameters) in a series of future articles. The future articles will also provide results that express the dependence of the composite's quality parameters on the insertion concentrations and possible process parameters (starting moisture, maximum compression pressure, loading speed, temperature, etc.), as well as results regarding the behaviour of composite materials made under different moisture, temperature, and time conditions in the storage environment or the surrounding environment.

MATERIALS AND METHODS

2.1. Used component materials, description and properties

To utilize bio waste, bricks were made from dehydrated sludge with filling material of seed shells and sawdust (fig. 1).

Sunflower seed husks has been chosen because Romania is among the major producers of sunflower oil, and husks represent 21.1-29.8% of the seed quantity.

Sunflower seed husks contain: 21.85-22% lignin, 31% hemicellulose, and 34% cellulose, a composition very similar to that of wood *(Coșereanu C., 2015).* The physical properties to consider when using a woody or agricultural biofuel are: density, porosity, compactness, moisture content, and calorific value.

According to *(http://docplayer.org/73032490),* the calorific value is better the higher the lignin content, with sunflower seed husks having a superior calorific value of 16120 kJ/kg in the anhydrous state, while wood has a value of 15500 kJ/kg. Sunflower seeds have a porosity of approximately 55-75%.

The sludge resulting from water treatment are complex colloidal systems with heterogeneous compositions, containing colloid particles with a diameter smaller than 1 mm, dispersed particles with a diameter between 1 and 100 mm, aggregates, suspended material, etc., having a gelatinous appearance, and containing a lot of water (*Batali L. et al., 2015*).

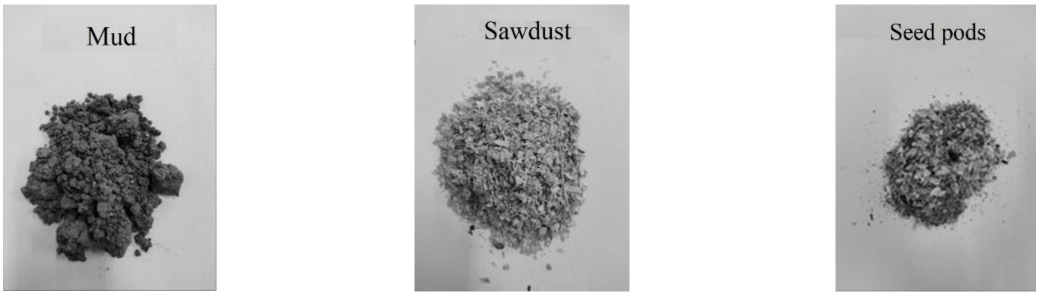


Fig. 1 - Utilized materials for obtaining composites with mud matrix and sawdust insert and/or seed husks

Moisture content (*Batali L. et al., 2015*): For materials retained on screens and grates: 60%; for fresh sludge: 95-97%; for excess activated sludge: 98%-99.5%; for precipitated sludge: 92%-95%. Specific density (*Batali L. et al., 2015*): raw primary sludge: 1.004-1.010 t/m^3; excess activated sludge: 1.001 t/m^3; after thickening: 1.003 t/m^3. According to technical literature data (*Batali L. et al., 2015; Arulrajah A., et al., 2011; Diliunas, J. et al., 2010*), there are also the following characteristics: density, r: 1.07-1.16 g/cm^3; upper plastic limit, wL: 100%-352%; lower plastic limit, wP: 49%-215%; compression index, Cc: 0.4-1.66; optimal Proctor moisture content, woc: 40%-53%; maximum dry density, gdmax: 8 kN/m^3.

Mechanical strength represents the capacity of biomass to resist internal tensions that occur in its structure as a result of external loads. The unit stress resulting from the application of an external load is normal stress (σ) and tangential stress (τ). In the case of simple stresses, such as compression or tension, they are determined by the ratio of the applied force (F) and the initial cross-sectional area of the specimen (S0) (*https://www.academia.edu/39766913/IRD_PROIECT; Panagiotis, 2011; Popescu I.N., 2014*). Simple stressors can be: axial (tension or compression); shear stresses; torsion stresses; bending stresses.

2.2. Granulometric analysis

In order to perform the granulometric analysis, the three materials, mud, seed shells, and sawdust, were thoroughly dried beforehand. The following equipment and instruments were used for determining the granulometric composition: analytical balance with a precision of ± 0.05 g (fig. 2); a vibrating sieve apparatus with a set of standardized sieves mounted in decreasing order of mesh size (fig. 3); a set of sieves with mesh sizes of: 1, 0.5, 0.315, and 0.125 mm.

Experimental procedure: 100 g of each material are weighed (fig. 4). The samples are loaded, one at a time, onto the top sieve, the lid is placed on, and the sieve set is fixed (fig. 5). The apparatus is set to a vibration level that allows particles to move across the sieve in a horizontal plane. The material is sieved for 10 minutes. The fixing system is removed, and the sieves are emptied, one at a time (fig. 6). Each granulometric fraction is weighed. The measurement tables are completed (Tables 1, 2, 3). The experimental results are processed by preparing the graphs (fig. 8, 9, 10). The minimum particle size is determined by interpreting the graphs.

The following notations will be used: ϕ for the sieve diameter in mm, R for the fraction retained on the sieve in g, and, T for the fraction passing through the sieve, in g.

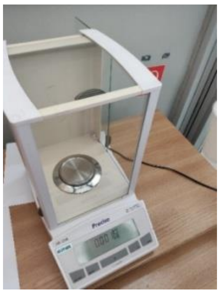


Fig. 2 – Analytical balance

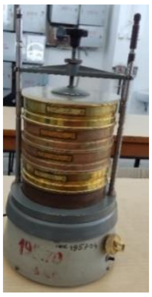


Fig. 3 - Vibration screening device

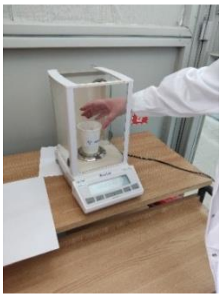


Fig. 4 - Weighing the sample

Fig. 5 - Powering the device

Fig. 6 - Emptying the sites

Analysing the diagrams from fig. 7 by interpolation, it is found that the average particle size has the value D_{med} = 0.463 mm for sludge particles. For the average diameter of the seed shell and sawdust particles, it was proceeded by extrapolation and the values 5.548 mm and 2.359 mm were obtained, respectively.

Table 1

Particle size measurements on sludge

ϕ, mm	R, g	T, g	$\sum q_i$, %	$1-\sum q_i$, %
1.000	36.200	11.039	36.2	63.8
0.500	11.039	12.552	11.0	89.0
0.315	12.552	15.097	12.5	87.5
0.125	15.097	24.613	15.0	85.0
0.000	24.613	0.000	24.6	75.4

Table 2

Particle size measurements for seed shells

ϕ, mm	R, g	T, g	$\sum q_i$, %	$1-\sum q_i$, %
1	91.370	4.547	91.3	8.7
0.5	4.547	3.295	4.5	95.5
0.315	3.295	0.811	3.2	96.8
0.125	0.811	0.000	0.8	99.2

Table 3

Particle size measurements on sawdust

ϕ, mm	R, g	T, g	$\sum R_i$, %	$100-\sum R_i$, %
1	74.416	8.856	74.4	25.6
0.5	8.856	6.762	8.7	91.2
0.315	6.762	7.562	6.7	93.3
0.125	7.562	3.098	7.5	92.5
0	3.098	0.000	3.0	97.0

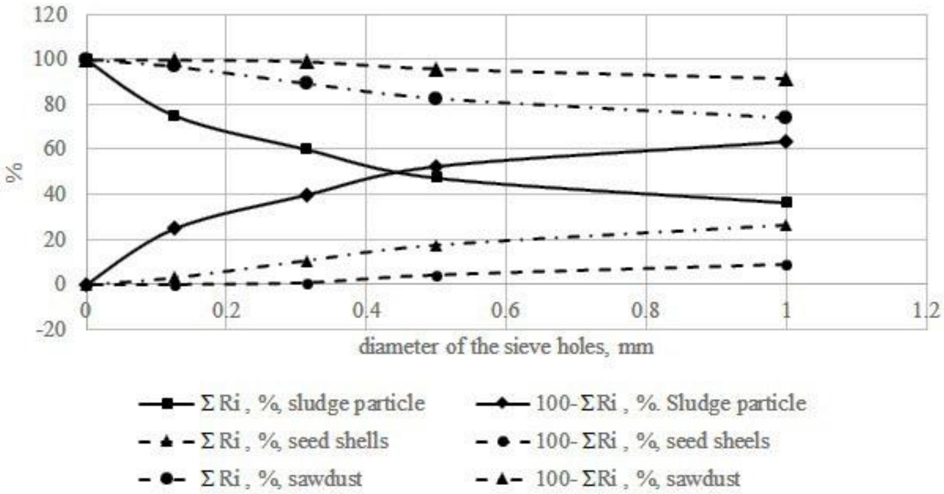
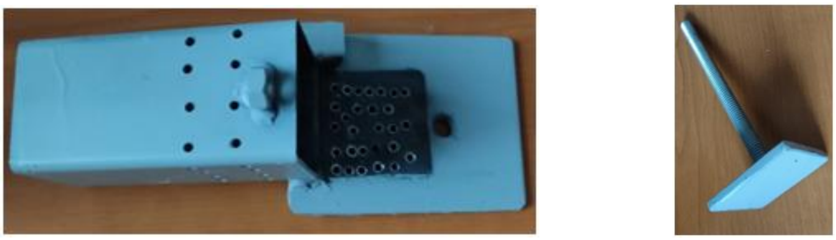


Fig. 7 - Processing of the mud results, the seed shells, and the sawdust results

2.3. Composite material preparation technology

The mould (fig.8a) is made of square pipe with dimensions of 45 x 45 x 2 mm and a height of 100 mm. The bottom is equipped with 2 mm diameter holes and is attached to the walls of the mould through a hinge that allows it to open for the removal of the pressed material. Two rows of holes of the same diameter were made on the walls of the mould to allow for the evacuation of excess water from the material. A piston pressed by weights was used to compact the material.

Experiment procedure: The concentrations of mud and additive material were determined: N100, N95S5, N90S10, N85S15, N80S20, N75S25, N70S30, N50S50, N95R5, N90R10, N85R15, N80R20, N75R25, N70R30, N65R35, N60R40, N50R50 (where N is the code for mud matrix, S is the code for seed coat insertion, and R is the code for sawdust insertion). Mixtures were made. 100 g of each type were weighed (using a digital kitchen scale). The moisture content of the materials was measured using a moisture meter, as shown in fig. 9.



a) b)

Fig. 8 - The mould for forming the composite material

a. matrix; b. plunger

The mixtures were pressed into the forming matrix, noting the initial dimensions of the sample, the pressing force, and time. After being removed from the matrix, the samples were measured and weighed. After two weeks, the samples are weighed and measured again (fig.10). The data is recorded in a table to study the evolution over time.

Fig. 9 - Moisture measurement

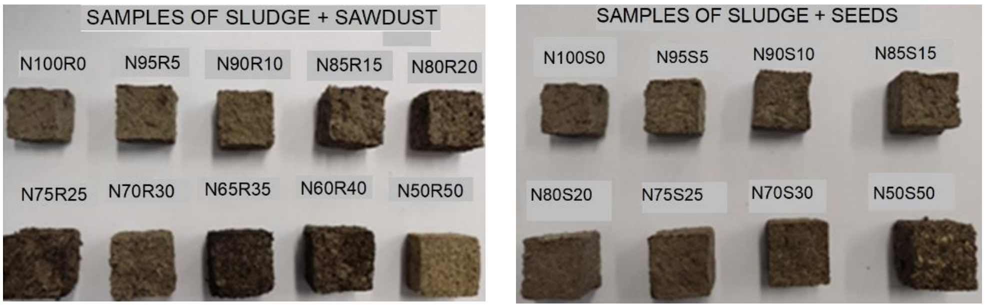


Fig. 10 - Samples of composite material after exiting the forming mould before pressing

RESULTS

In this chapter, quantified results of the prospective study of the manufacturing process of composite materials with mud matrix and seed shell insertion are presented. Technological parameters are those parameters of the composite material manufacturing process with mud matrix and insertion of various materials that characterize the product before and immediately after compression. For now, an exact list of the parameters of the technological system model used for composite manufacturing cannot be given. This is because some of the system parameters were kept constant during these initial experiments (initial material mass, compression time, compression matrix section dimensions, average particle size of the materials, physico-chemical parameters of the matrix material). Other parameters were varied too little for a complete study (initial moisture), or were not controlled (temperature). For the moment, it can be affirmed that the main input parameter considered was the insertion concentration in the composite material. In addition to this, the mass of material introduced into the mould, the initial volume, and its moisture are the main input parameters involved. Also, an important measure of the quality of the technological transformation process is the final density of the product.

If the variation of the final moisture (fig.11) and final density (fig.12) with the insertion concentration in the composite is graphically represented, it is observed that the obtained curves do not present significant peculiarities. However, they do show minima and maxima that cannot even be hypothetically explained at the current level of research. Under these conditions, it is more useful, at this stage, to perform a statistical analysis of the output parameters in relation to the experimentally varied input parameters.

For the moment, the input parameters with the largest variations are considered: insertion concentration in the composite material, c, pressing mass (which gives the pressing force), m_p, initial volume of the material in the mould, V_i, and material moisture before compression, u_i. Considering the final parameter as the final moisture of the composite product, u_f, a multivariate analysis based on multilinear regressions is used to obtain the dominant parameters that influence the final moisture.

In compliance with (*https://ro.kamiltaylan.blog/coefficient-of-determination*), a multilinear regression of the form is desired:

$$u_f = c_0 + c_1 c + c_2 m_p + c_3 V_i + c_4 u_i \tag{1}$$

where: $c_i, i = 0,1,2,3,4$ are coefficients of the free parameters (input). Taking into account the Pearson correlation matrix and the results of multiple regression analysis (*https://profs.info.uaic.ro/~val/statistica/StatGloss.htm#_Toc2658366*), the following relationship has been obtained:

$$u_f = 26.414253 - 283834.1917 V_i + 0.846478 u_i. \tag{2}$$

Input parameters c and m_p have been eliminated because they are correlated with V_i and u_i (see table 4). The Pearson correlation matrix can be observed in Table 4. Regression (2) corresponds to the determination coefficient R^2=0.603. The regression with three independent variables is indicated by the same analysis in relation (3):

$$u_f = 37.114209 + 0.976764 m_p - 406259.2635 V_i + 0.733969 u_i \tag{3}$$

with the determination coefficient, R^2=0.716.

The complete regression with 4 independent variables (the ones selected for analysis) is given in (4):

$$u_f = 16.648239 - 0.321762 c + 2.588281 m_p - 341411.5318 V_i + 0.841759 u_i \tag{4}$$

with the determination coefficient R^2=0.644.

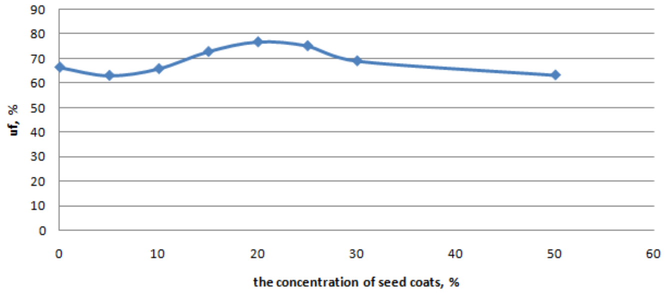


Fig. 11 - The dependence of the final moisture of the composite on the concentration of the insert

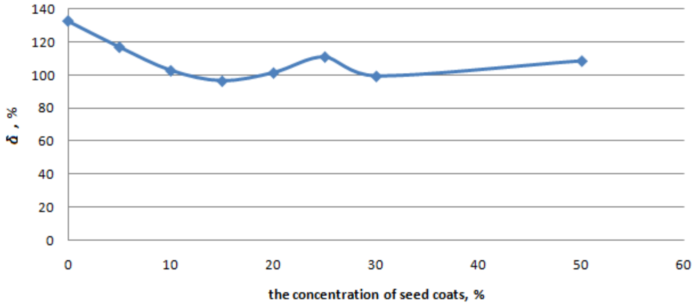


Fig. 12 - The dependence of the compression densification of the composite on the insertion concentration

Table 4

The Pearson correlation matrix for the case where the dependent variable is final density

	u_f	c	m_p	V_i	u_i
u_f	1	0.02035	0.0671116	-0.473602	0.533576
c	0.02035	1	0.982569	0.749836	0.460682
m_p	0.0671116	0.982569	1	0.667505	0.377645
V_i	-0.473602	0.749836	0.667505	0.995495	0.288896
u_i	0.533576	0.460682	0.377645	0.288896	1

The coefficient of determination, R^2, is a measure used to explain how much variability of one factor can be caused by its relationship with another related factor, according to (*https://en.wikipedia.org/wiki/Coefficient_of_determination; https://profs.info.uaic.ro/~val/statistica/StatGloss.htm#_Toc265836*)

This correlation, known as "goodness of fit," is represented as a value between 0.0 and 1.0. Regression equation (2) explains 60.3% of the variability of the final moisture content u_f, using only predictors (independent variables): V_i and u_i. Regression equation (3) explains 71.6% of the variability of the final moisture content u_f, using predictors: m_p, V_i si u_ii

The linear regression equation that depends on all the predictors considered in the model, (4), c, m_p, V_i and u_i, explains only 64.4% of the variability of the final moisture content u_f.

For the regression with the best performance, (3), the adjusted coefficient of determination is 0.603494, and the multiple correlation coefficient is R = 0.846629.

For the general regression, there is a right tail: F(2,5) = 6.327101, p-value = 0.046879 < 0.05, therefore the null hypothesis is rejected: H_0, which means that the linear regression is better than approximating with a constant value and hypothesis H_1 is accepted. Also, considering the variables that provide the best approximation, the analysis concludes that the variables c and m_p are not significant predictors for the dependent variable u_f. The multivariate analysis program notes that if any excluded variable is highly suspected to be related to the dependent variable (u_f), either theoretically or due to previous research, it is recommended to include the variable in the model, regardless of the p-value. To do this, the iteration setting must be modified according to the manual.

Linear regression assumes normality for residual errors. The p-value of the Shapiro Wilk test is 0.911. It is assumed that the data is normally distributed. Therefore, the test is validated regarding residual normality. The p-value of the White test is 0.596161 (F = 0.574642). It is assumed that the variance is homogeneous. Therefore, the test is validated regarding homoscedasticity (*https:// www.statskingdom.com/410multi_linear_regression.html*) and variance homogeneity. There is no multicollinearity problem since all VIF values are less than 2.5. The a priori power (regarding the model with all four predictors) must be calculated before running the regression. Although the testing power of the whole model is low: 0.1062, H_0 is rejected.

An alternative to linear regressions are power regressions, which in this case have the general form:

$$u_f = k \cdot c^{\alpha_c} \cdot {m_p}^{\alpha_{m_p}} \cdot \; V_i^{\alpha_{V_i}} \cdot {u_i}^{\alpha_{u_i}} \tag{5}$$

in which k, is a coefficient and α_c, α_{m_p}, α_{u_i} are exponents, all being determined from the experimental data through the method of least squares same as the coefficients of the linear regression (1). The synthesis of the results of the multivariate analysis for the form (5) of the regression is given in Table 5.

Table 5

The coefficients and exponents of the power-type regressions (homogeneous functions) for the final humidity

Solution's coefficient and exponents					
k	α_c	α_{m_p}	α_{V_i}	α_{u_i}	R^2
0.0209551	0.00170018	0.082028	-0.452973	0.840125	0.655
0.0176824	0	0.0842791	-0.467878	0.846776	0.741
0.0330896	0	0	-0.379778	0.933357	0.642

From table 5, it can be observed that the best solution is given by the dependence only on the variables m_p, V_i and u_i, therefore still an incomplete solution as in the linear regression. The statistics exclude the variable c from many formulas due to its closer correlation with the other independent variables (Table 4, the concentration row or column generally contains the highest values).

Table 6

The intercept and coefficients of linear regressions for final density

Solution's coefficient and exponents					$\mathbf{R^2}$
Intercept	**Coefficient c**	**Coefficient m_p**	**Coefficient V_i**	**Coefficient u_i**	
2054.388894	2.319398	-77.322147	-2697596.046	1.41414	0.893
1906.861562	0	-65.705652	-2230146.274	2.191135	0.919
2062.103133	0	-64.434048	-2177807.476	0	0.932
1943.392501	0	-71.535244	0	0	0.939

The same type of statistical analysis is carried out further for the final density as the dependent parameter, considering the same four independent parameters. For linear regression, the general formula is the same as that given in (1), except that ρ_f appears instead of u_f.

Therefore, the load mass during pressing, m_p, explains 94% of the behaviour of the final density, making it the most accurate solution. This solution has, for the general regression, a right tail F(1,6) = 93.929532 and a p-value of 0.00000692232 < 0.05, hence the null hypothesis, H_0, is rejected as in the previous case.

The regression relationships can be written simply using Table 6, for example, the relationship with the highest coefficient of determination (R^2 = 0.94, R^2_{adj} = 0.93, F(1,6) = 93.93, p < 0.001) shows that the final density depends most strongly on the pressing mass, therefore on the force with which the forming composite is pressed in the mould.

Table 7

The Pearson correlation matrix for the case where the dependent variable is the final density

	ρ_f	c	m_p	V_i	u_i
ρ_f	1	-0.959894	-0.969514	-0.726446	-0.32719
c	-0.959894	1	0.982569	0.749836	0.460682
m_p	-0.969514	0.982569	1	0.667505	0.377645
V_i	-0.726446	0.749836	0.667505	0.995495	0.288896
u_i	-0.32719	0.460682	0.377645	0.288896	1

$$\rho_f = 1943.392501 - 71.535244 m_p. \tag{6}$$

The best power regression for final density is found in the same way as for final humidity, having the formula given by (7).

$$\rho_f = 33.394007 \cdot m_p^{-0.307592} \cdot V_i^{-0.458863} \tag{7}$$

All the power regression solutions given by (*https://profs.info.uaic.ro/~val/statistica/StatGloss.htm#_Toc2658366*), have coefficient given in table 8.

Table 8

The coefficients and exponents of the power regressions (homogeneous functions) for the final moisture content

Solution's coefficient and exponents					$\mathbf{R^2_{adj}}$
k	α_c	α_{m_p}	α_{V_i}	α_{u_i}	
210.249096	0.00199632	-0.335184	-0.286420	-0.0477218	0.886
145.848877	0.0184161	-0.334727	-0.303509	0	0.914
33.394007	0	-0.307592	-0.458863	0	0.923

The composite material studied in these experiments proves to be possible to obtain through the proposed technological process. In these experiments, the authors aimed to vary some of the input parameters to verify the dependence of the output parameters (dependent variables) on predictors (input parameters) and the conditions of the technological process. The main input parameters considered in these experiments were: the concentration of the insertion in the composite material, the initial moisture content, the initial volume of the material, and the pressing mass, which actually means pressing force (by amplifying with gravitational acceleration) and ultimately compression pressure. The other important input parameters were kept constant for now (initial composite mass, cross-sectional dimensions of the matrix and insertion, compression temperature and time, and implicit compression speed), all of which could have significant influences in the compression process. Additionally, initial moisture content was slightly varied.

The parameters of particular interest in these experiments are the final moisture content (to estimate the intensity of dehydration in the technological process) and the final density (to evaluate the densification capacity of the technological process). Dehydration and especially densification are expected to have a significant influence on the mechanical and thermal properties of the final composite material.

In future studies, based on the conclusions from multivariate regression statistics, synthetic parameters of the composite material formation process will be formulated, such as a measure of dehydration.

$$\delta = \frac{u_i - u_f}{u_i} \tag{8}$$

A graphical representation of the dependence of dehydration (8) on initial moisture content, using linear regression relationships, is given in fig. 13.

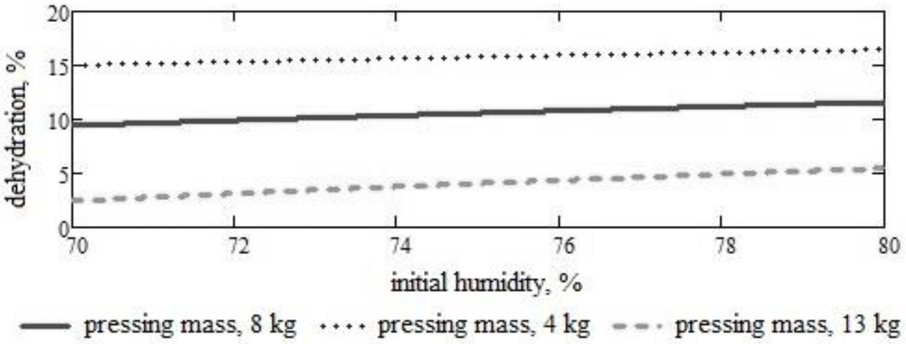


Fig. 13 - Variation of dehydration with the initial moisture content of the raw material from which the final composite is formed

CONCLUSIONS

C1) The experiments whose results are presented in this article demonstrate the feasibility of the proposed composite material using the described manufacturing process.

C2) The dependencies between the output and input parameters of the manufacturing process of the composite material with mud matrix and agricultural waste insertion are complex and can have a random character, as shown by the graphical representations of the final humidity and density as functions of the insertion concentration in the composite material. Currently, these studies are left for later, when more experimental results are accumulated, with more parameters being varied.

C3) Given the conclusion of C2, it has been opted for the statistical study of the experiments, which should give us some information on the connections between the output parameters (which represent the quality of the composite material at the output of the process and the quality of the manufacturing process) and the input parameters.

For this purpose, multivariate regression analyses were performed for the final humidity and density as output variables (dependents) and the insertion concentration in the material, pressing mass, initial volume, and initial humidity as independent variables (predictors).

The results show that:

- The final humidity depends most intensively on pressing mass (positive coefficient), initial volume (negative coefficient), and initial humidity (positive coefficient) in the case of multivariate linear regression, and on pressing mass (positive exponent), initial volume (negative exponent), and initial humidity (positive exponent);

- The final density depends most intensively on pressing mass (negative coefficient) in the case of multivariate linear regression, and on pressing mass (negative exponent) and initial volume (negative exponent) in the case of power multivariate regression.

In addition to the insertion concentration in the material and the initial moisture content, an attempt is made, if possible, to characterize the influence of other process parameters (matrix temperature, material pressing speed into the matrix, for example);

C4) The feasibility of the composite brick forming process also included the creation, at a low technical level, of the extrusion installation. This rudimentary installation was capable of producing variations of the desired composite material, with properties that make it further testable in various thermomechanical and acoustic trials.

Clearly, the improvement of the installation, possibly for standardized brick sizes, is a separate activity that cannot be done without preliminary research to demonstrate that the material can be obtained and has the required properties.

C5) The proposed regression relationships from the multivariate analysis are used to guide the choice of resolutions and intervals for input parameters in the manufacturing process and to form dimensionless input-output parameters that synthetically describe the quality of the material and process.

C6) It is clear that there are several future directions for this work. These include exploring additional input parameters beyond insertion concentration and humidity, as well as examining the effects of pressing force and loading speed. Additionally, it would be beneficial to increase the resolution of these parameters to gain a more detailed understanding of their impact. Finally, it is important to measure the quality of the resulting materials, specifically their mechanical resistance to compression, as well as their thermal and sound insulation properties.

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