# MECHANICAL AND THERMAL PROPERTIES OF COMPOSITE MATERIALS OBTAINED WITH SLUDGE MATRIX AND AGRICULTURAL WASTE INSERTS
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# *PROPRIETĂȚI MECANICE ȘI TERMICE ALE MATERIALELOR COMPOZITE OBȚINUTE CU MATRICE DE NĂMOL ȘI INSERȚII DIN DEȘEURI AGRICOLE*

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## ABSTRACT
*The article describes the achievement and values of the mechanical and thermal characteristics of composite materials with sludge matrix and the insertion of agricultural waste, focusing on the compressive strength and thermal conductivity coefficient. These two characteristics are essential for civil engineering applications. The compressive strength and thermal conductivity coefficient depend significantly on the insertion concentration in the composite material: the compression strength decreases, and the thermal conductivity coefficient increases as the insertion concentration increases.*
*For mud matrix composites and seed husk insert, the compressive strength varies between 0.375 MPa and 2.292 MPa. In the case of sawdust insert, the compressive strength varies between 0.149 MPa and 2.292MPa. These values indicate that composite materials are at the lower limit of strength of building materials, but have good insulating properties due to the low coefficient of thermal conductivity. These features recommend using them for supporting walls in light, floor-free buildings, and for partitions with good thermal insulation properties.*

## REZUMAT
*Articolul descrie obținerea și valorile caracteristicilor mecanice și termice ale materialelor compozite cu matrice de nămol și inserție de deșeuri agricole, punând accent pe rezistența la comprimare și coeficientul de conductivitate termică. Aceste două caracteristici sunt esențiale pentru aplicațiile în construcții civile. Rezistența la comprimare și coeficientul de conductivitate termică depind semnificativ de concentrația de inserție în materialul compozit: rezistența la comprimare scade, iar coeficientul de conductivitate termică crește pe măsură ce crește concentrația de inserție.*
*Pentru compozitele cu matrice de nămol și inserție de coji de semințe, rezistența la comprimare variază între 0,375 MPa și 2,292 MPa. În cazul inserției de rumeguș, rezistența la comprimare variază între 0,149 MPa și 2,292 MPa. Aceste valori indică faptul că materialele compozite se situează la limita inferioară de rezistență a materialelor de construcții, dar au bune proprietăți izolatoare datorită coeficientului scăzut de conductivitate termică. Aceste caracteristici recomandă utilizarea lor pentru pereți de susținere în clădiri ușoare, fără etaje, și pentru pereți despărțitori cu bune proprietăți de izolare termică.*

## INTRODUCTION
Sustainable sludge recovery is a solution for the increased management of sludge stocks resulting from the wastewater treatment of urban, industrial systems and dredging works of lakes, canals, and rivers. According to FAO's AQUASTAT database (Global Information System of the EU Water and Agriculture Organisation) of 2020, 56% from global freshwater abstraction are released into the environment as waste water (in the form of industrial effluents and agricultural drainage waters), while the remaining 44% are consumed in agriculture, the report said, for irrigation of land (*https://data.apps.fao.org/aquastat/?lang=en*). Increased discharges of industrial waste water, improperly cleaned, clean wastewater and wastewater infiltrations from agricultural activities (from soils directly into groundwater) have led to water quality degradation around the world. Even today, in many developed countries, most wastewater is discharged directly into the environment without proper treatment.

Another important issue is the management of sewage sludge, where most of the pollutants present in wastewater are concentrated. A typical sludge treatment scheme provides for the preliminary reduction of the water content of the original sludge, biological/chemical stabilization, with or without electricity production, and a later phase of chemical conditioning and mechanical dehydration, designed to further reduce the water content of the sludge. Clearly, the intention is to minimize the volume of sludge to be removed outside the sewage treatment plant.

As for the methods of managing excess sludge, the most used are waste storage, incineration, evacuation to seas and oceans, re-use in agriculture (directly or after composting) and reuse for the production of cement, bricks and asphalt. According to (*https://www.researchgate.net/figure/Sludge-management-2016-Eurostat-Data-Explorer-2020_fig2_353333820)* in 2020, about 40% of the total sludge produced in the European Union is used in agriculture. Another method of removing sludge, which has also been most used for many years, is storage. Recently, due to the impact of leachate production and equivalent CO2 emissions, legislation has become stricter, and the method of sludge storage began to be less used in many European countries. On the other hand, in recent years, sludge incineration has been increasingly used in European countries, due to significant improvements in this process, such as the high technological level, reducing costs and reducing emissions.

The recovery method proposed consists of drying by vibratory sieving and use to obtain materials useful in construction (*Dumitrescu-Tivig D-C*, *2024*). The materials are varied, including mud matrix composite materials of different concentrations, obtained from seed husk or sawdust shredders. A number of sludge characteristics are detailed in the material in the paper (*Batali and Carastoian, 2015*). Characterizations of the physical properties of such materials also appear in papers (*Parra-Saldivar and Batty, 2006; Silveira et al., 2012; Parisi et al., 2014; Correa et al., 2006; Zhou et al., 2022; Kumar et al., 2024*), as well as in many other works, many authors operating on composite materials with sludge matrices, clay, etc.

The article begins with the description of experiments conducted to determine the mechanical properties and thermal conductivity coefficient of bricks made from sludge and agricultural materials. It continues with the results obtained and concludes with comments and conclusions drawn from data processing and comparing them with other types of materials used in construction.

## MATERIALS AND METHODS

To evaluate the mechanical and thermal properties of mud matrix composite materials and agricultural waste inserts, compression experiments were conducted, as well as experiments for determining the coefficient of thermal conductivity.

*Experiments for determining the compressive strength*

a) b) c)

**Fig. 1 - Devices for mechanical testing**

*a - laying and alignment of the parts on the press support of the mechanical test machine ZDM 50,000 N from the mechanical test laboratory of the Faculty of Construction Bucharest; brick before compression; b - applied force; c - brick after compression.*

The mechanical properties of bricks or briquettes built from mud matrix composite material and seed husk or sawdust insert are multiple. In the experiments whose results are described in this article, only the strength of the bricks at crushing (compression) was measured.

Two mechanical characteristics of the bricks produced have already been measured: the density of the bricks made of composite material and the mass of the final product (*Farcas-Flamaropol et al., 2023; Ghiga, 2021*). The first mechanical characteristics as mentioned importance are: mass, density and resistance to compression. Important are then the elastic characteristics: the modulus of elasticity, Poisson's coefficient, tensile strength and compressive strength (*Ghiga, 2021*).

The compression test was performed using the ZDM 50,000 N test machine for measuring the resistance to compression, bending and traction. For each material concentration, three samples were used to calculate the average compressive strength. The evidence was put on a media stand. The compressive force (figure 1-b) has been read.

Then, the following features were calculated: the area of the compression section:

$$A = b \cdot h \tag{1}$$

where: $A$ - area of the compression section, mm$^2$;
$b, h$ - dimensions of the brick, mm.

and compressive strength:

$$R_{compr} = \frac{F}{A} \tag{2}$$

where: $R_{compr}$ - compressive strength, N/mm$^2$ (MPa);
$F$ – compression force, N.

The strength of the bricks at compression was determined as an average value, corresponding to the three samples tested. Experimental data was stored in tables and then used for synthetic graphical representations.

*Experiments for determining the coefficient of thermal conductivity*

For the determination of thermal transfer of mud bricks with seed husk insert or sawdust, a box of fire-resistant material (plasterboard) was used, having on the upper wall a slit in which the bricks are tightly inserted. Inside the box there is a heat source that heats the box on the inside to 100 °C. The ambient temperature and the measuring distance will be the same. The outside temperature on the bricks is measured with a digital infrared thermometer. For each material concentration, three temperatures will be measured, on three bricks as shown in figure 2. The thickness of the brick must be measured and the average density of the three bricks calculated. The data is stored in tables and subsequently used for statistical processing.

a) b)

**Fig. 2 - Measuring the external temperature on bricks**

*a - laying of bricks b - temperature measuring devices*.

Calculations of thermal conductivity coefficients are made according to the formulas (3.1)-(3.3) in the source written by *Dobritoiu, (2024*). These formulas use the thicknesses of the walls of the box in which the heat source is found and the coefficient of thermal conductivity of the wall made of plasterboard, as well as temperatures measured at three points on the surface of the composite bricks. The ratio between the temperature generated by the heat source inside the box and the temperature measured on the outer surface of the bricks together with the thickness of the brick, allows determining the thermal conductivity coefficient of the brick.

The experimental data comprised numerical sequences, with the first sequence representing the concentration of the insertion material and the second sequence representing either the compressive mechanical strength or the thermal conductivity.

The statistical tool used to investigate the relationships between mechanical strength and insertion concentration, as well as thermal conductivity and insertion concentration, was both nonlinear and linear regression analysis. Observing the graphical distribution of the experimental data, a second-degree polynomial interpolation function was found suitable for the dependence of mechanical strength on insertion concentration. For the dependence of thermal conductivity on insertion concentration, the graphical representation indicated the use of linear regression (first-degree polynomial).

The accuracy of the proposed statistical models was estimated using the coefficient of determination $R^2$. The accuracy of the regression formulas increases as $R^2$ approaches the value of 1. It was observed that the interpolation formulas for the dependence of mechanical strength on insertion concentration are more accurate than the regression formulas for the thermal conductivity coefficient.

Regarding the errors generated in the experiments, these were tested only to detect any potential outliers, but no such anomalies were found. On the other hand, there were experimental data points, so it was preferred not to eliminate any of them.

## RESULTS

In this paragraph, the results of the statistical processing of experimental data obtained by measurement and preprocessing shall be presented. It highlights the variations in mechanical and thermal characteristics of composite materials with clay matrix and seed insert, respectively sawdust, depending on the concentration of the insert in the material. The trendlines for assessing the overall variation of thermal and mechanical characteristics according to the concentration of the insert are also presented.

*The behaviour of mechanical compressive strength according to the concentration of the insert in the material*

The variation in compressive strength according to the insertion concentration of the bricks in the mud matrix composite material and seed shell insert is plotted in Figure 3.

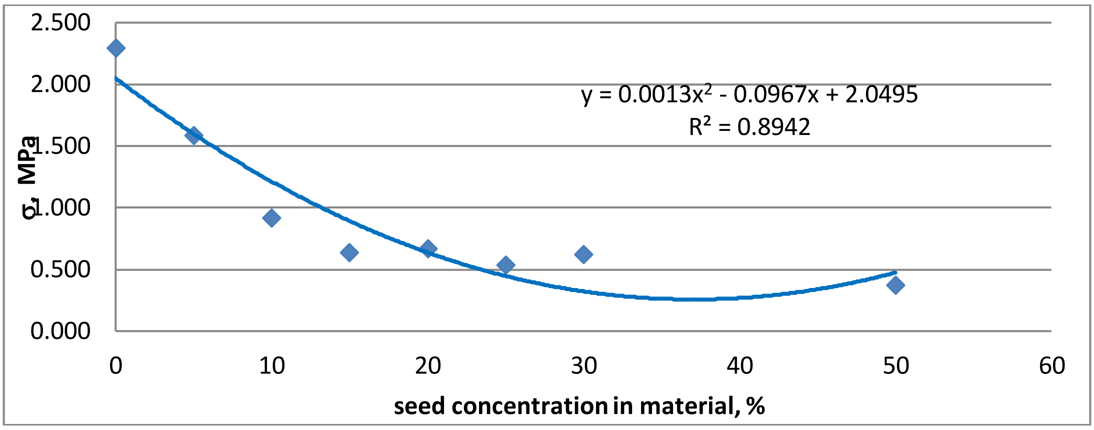


**Fig. 3 - Variation of the crushing limit resistance of the sludge matrix composite material and seed husk insert, with the concentration of seed husks**

The resistance of the bricks to compression, obtained from the composite material with sludge matrix and seed shell insert, decreases with increasing the concentration of seed shells. The decrease in quantity does not have a linear influence. The trend line, expressed by the regression line equation, indicates that the compressive strength decreases as the seed husk content in the composite material increases. Compression resistance values for sludge matrix and seed husk insert composite variants range from 0.375 MPa to 2.292MPa.

The variation in compressive strength, depending on the insertion concentration of the bricks in the mud matrix composite material and sawdust insert, is plotted in Figure 4. In this case, the compressive strength of the bricks decreases with the increase in the concentration of sawdust. The decrease does not have a linear relationship. Compression resistance values for mud matrix composite variants and sawdust insert range from 0.149 MPa to 2.292 MPa.

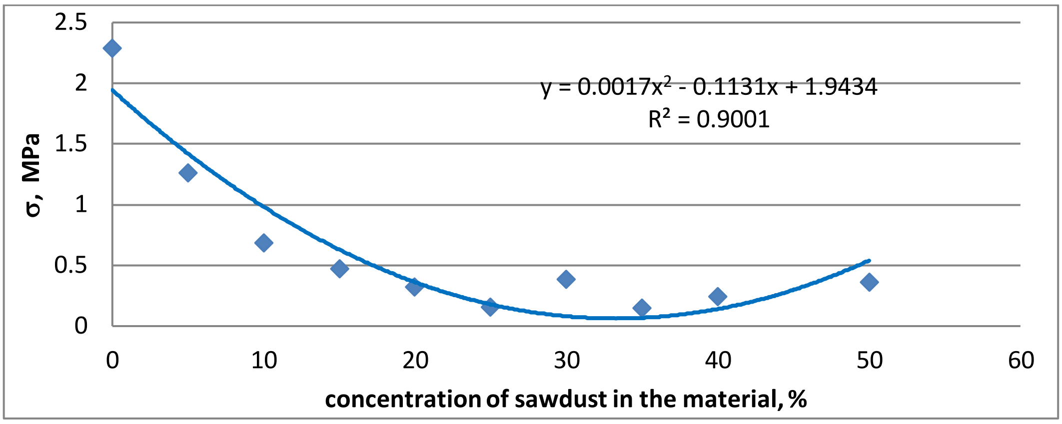


**Fig. 4 - Variation of the crushing limit resistance of the matrix composite material sludge and sawdust insert, with sawdust concentration**

*Variation of thermal conductivity coefficient to sludge matrix composite materials*

The variation in thermal conductivity of the sludge matrix composite and seed husk insert according to the concentration of the seed husks can be observed in Figure 5. According to the trend line, thermal conductivity increases with the insertion concentration, but relatively slowly. The minimum thermal conductivity is 0.4089 W/mK, while the maximum is 0.59989 W/mK.

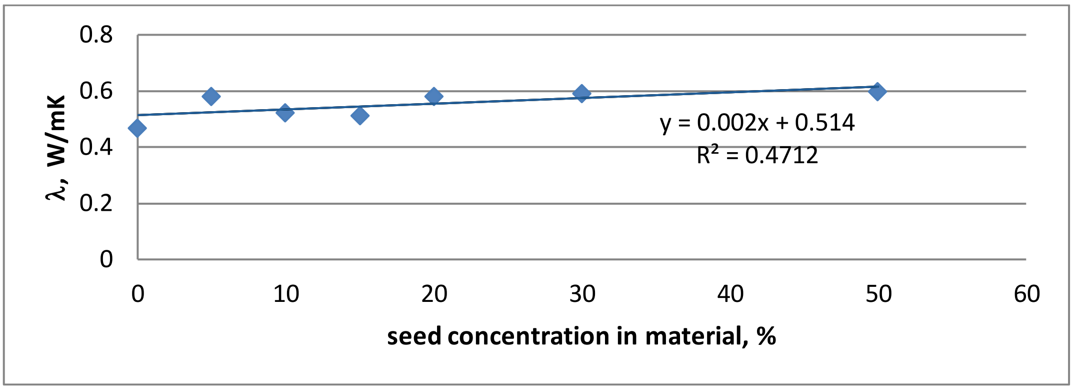


**Fig. 5 - Variation of thermal conductivity of the composite material (sludge matrix with seed husk insert) with the concentration of seed husk insert**

The variation in thermal conductivity of the sludge matrix composite and sawdust insert according to the concentration of sawdust can be observed in Figure 6. According to the trend line, the thermal conductivity increases with the insertion concentration. The minimum thermal conductivity is 0.430946 W/mK, while the maximum is 0.674512 W/mK.

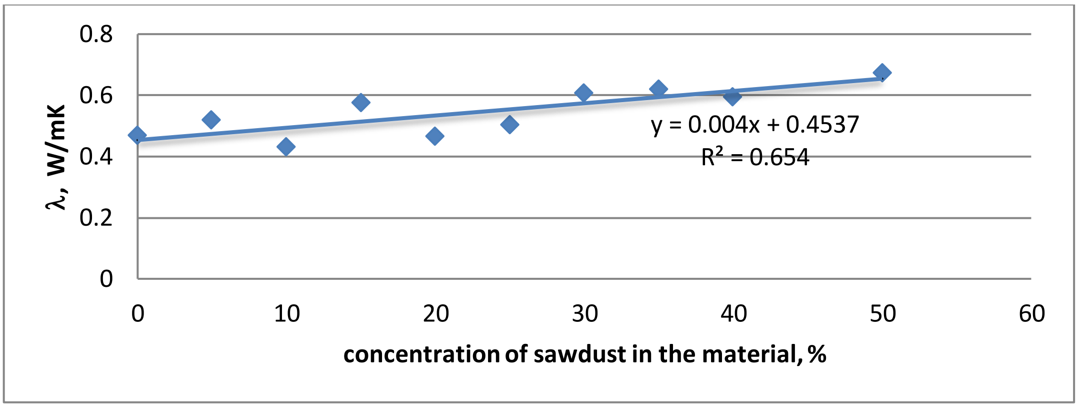


**Fig. 6 - Variation of thermal conductivity of composite material (sludge matrix with sawdust insert) with the concentration of sawdust insert**

For comparison, according to the paper (*https://www.imaterial.ro/exterioare/caramizi-perfromante-termic.html*), the thermal conductivity of hollow bricks Heluz Family is 0.066/0.089 W/mK (with/without polystyrene insert), and they have an acoustic insulation index of 37 dB. Ordinary ceramic bricks have a thermal conductivity ranging from 0.15 to 0.202 W/mK and an acoustic insulation index ranging from 51 to 55 dB. Also, according to the source (*https://www.heluz.com/files/57255_00-Technicky-list-EN.pdf*), the thermal conductivity of the ground Heluz P15 25 brick is 0.26 W/mK, and the Heluz P15 30 bricks of the same family, have a thermal conductivity of 0.165 W/mK, according to the paper (*https://www.heluz.com/files/vyrobky/prohlaseni-o-vlastnostech/311897-20305.00+_en-v4.pdf*). Measured values for the thermal conductivity of the sludge matrix composite material and seed husk insert, as well as those with sawdust insert, fit well in the given intervals in literature for the thermal conductivity of materials of this type, as evidenced by the works (*Parra-Saldivar & Batty, 2006; Revuelta-Acosta et al., 2010; Jové-Sandoval et al., 2023*).

The mechanical and thermal properties of composite materials with sludge matrix and agricultural waste insert are a potential resource in construction, having multiple applications such as small load-bearing wall, wall filler, thermal insulation and acoustic insulation. For this purpose, important properties of these materials, such as compressive strength and thermal conductivity, were tested.

*Mechanical properties*

Compression resistance is one of the most important characteristics for assessing the load bearing of materials used in construction.

For comparison, table 1 provides values of compressive strength of materials commonly used in construction, according to the paper (*https://www.rombadconstruct.ro/rezistenta-la-compresiune.html*). For example, Heluz P15 30 bricks have an average compression strength of 15 MPa and a normalized value of 17.2 MPa (*Danciu et al., 2017*). These values are used to highlight the performance and potential of compressive strength of composite materials, in comparison with traditional materials used in construction.

**Table 1**

**Compression resistance for a few reference materials in construction**

| Material | Compression resistance, MPa |
|---|---|
| Poros limestone | 2.7 |
| Lightweight concrete | 8.1 |
| Clay brick | 9.8 |
| Common heavy concrete | 31.9 |
| Limestone | 76.0 |
| Silico-calc brick | 11.0 |
| Pinewood | 44.1 |
| Granite | 181.4 |

The mud matrix composite bricks and seed husk insert are positioned at the lower limit of the materials used in the construction field.

In literature, there is little work studying the mechanical properties of composite bricks based on mud matrices or clay with vegetable and/or dung inserts. One of the remarkable works confirms the results obtained in the experiments carried out. The authors of this paper provide for the compressive strength of bricks of this type, coming from various areas of the planet, values ranging from 0.29 to 3.04 MPa, respectively, range within which the performance of the proposed composite material variants for research also fit (*Silveira et al., 2012*). The correct framing of the measured compressive strength of the sludge matrix composite materials and seed shell insert is also confirmed by (*Oliveira et al., 2021*), which includes a wide range of such materials, some of which are of recent conception.

*Thermal properties*

For thermal properties, taking into account the available experimental data and the fact that the elaborated composite materials are intended for applications in the field of civil engineering and related fields, thermal conductivity was chosen. This is an appropriate measure for characterizing the ability of a material to be a good heat insulator or conduct heat.

According to the trend line, the thermal conductivity of the sludge matrix composite material and seed shell insert increases with the insertion concentration, in a relatively slow way. The minimum value of thermal conductivity is 0.4089 W/mK, while the maximum value is 0.59989 W/mK. For the material with sawdust insert, the thermal conductivity increases with the insertion concentration. The minimum value of thermal conductivity is 0.430946 W/mK, while the maximum value is 0.674512 W/mK.

Compared to the usual building materials, the composite with sludge matrix and seed shell insert, as well as the one with sawdust insert, have a thermal conductivity value comparable to that of plasterboard or dry, according to the work (*https://www.rombadconstruct.ro/tabel-cu-conductivityate-termica-a-materialelor-de constructii.html*). It also falls within the range of thermal conductivity of other materials such as Agloporite concrete, asbestos, cast gypsum, gravel (stuffing), limestone, hollow core stones made of light concrete, solid stones made of light concrete according to DIN 18152, solid stones made of natural tuff or expanded clay, expanded clay concrete on quartz sand with pore-laying, concrete, brick for furnace, etc. (*https://builder.techinfus.com/ro/uteplenie/teploprovodnost-uteplitelej.html*). The thermal conductivity range covered by the sludge matrix composite material and seed shell insert is less common in most building materials (*https://www.rombadconstruct.ro/tabel-cu-conductivityate-termica-a-materialelor-de constructii.html; https://builder.techinfus.com/ro/uteplenie/teploprovodnost-uteplitelej.html*).

## CONCLUSIONS

Composite materials with sludge matrix and agricultural waste inserts are an alternative solution to early III millennium building materials. However, from the point of view of their structure and source, they are older than most of the materials used today in construction, small-sized ones with clay or mud walls are used for thousands of years. In this context, a new impetus in the research activity was the subject of knowledge as accurately as possible of the properties of these materials and the variation of these properties according to various parameters of the composition of materials or the technological training process. These materials have important applications both in the construction of small-sized houses, possibly with strength structures reinforced with wooden or concrete beams, and in the realization of the filler walls, separation and isolation. The possibility of dressing them in a hygienic way makes them usable as walls without load-bearing (insulators, separators, etc.) in modern and sanitary safe and fire-resistant buildings.

Mechanical bending strength, but especially when compressing, recommends bricks as strength materials for small houses, cottages, etc. Thermal conductivity recommends composite materials for the insulating wall (thermal, acoustic). Low density leads to the realization of light walls and the possibility of obtaining low loads for a strength structure made of wood, concrete or metal. Obviously, in the future, a health approach study for these materials must also be carried out, in order to eliminate possible sources of infection for residents of buildings built with such materials.

The basic properties of these composite materials are strongly influenced by the concentration of the insert, giving the manufacturer the opportunity to supply composites with programmable properties. However, among the parameters that characterize the raw material and the technological process, there are some important ones that have not been taken into account in the research whose results have been described, such as insert grain and material pressing speed in forming matrix. These issues remain to be resolved in the future, especially if the applications suggested in the exposed research will prove viable.

The important conclusions in this article are as follows:

C1) The thermal conductivity for the composite material with seed husk insert increases with the insertion concentration, relatively slowly. The minimum value of thermal conductivity is 0.4089 W/mK, and the maximum is 0.59989 W/mK.

C2) The thermal conductivity of the composite material with sludge matrix and sawdust insert increases with the insertion concentration. The minimum value of thermal conductivity is 0.430946 W/mK, and the maximum is 0.674512 W/mK.

C3) The compressive strength of the bricks in the sludge matrix composite material and seed shell insert decreases as the concentration of seed shells in the composite material increases. The values of the compression resistance vary between 0.375 MPa and 2.292 MPa, placing the bricks of this composite at the lower limit of the usual building materials.

C4) For composite materials with sludge matrix and sawdust insert, the compressive strength of the bricks decreases with increasing sawdust concentration. The decrease is not linear, and the values of the compressive strength for these composite variants vary between 0.149 MPa and 2.292 MPa.

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