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Properties of grey marl bricks with additions of rice husks

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Abstract. This article presents the results of experimental research on the impact of environmentally efficient materials developed on the basis of grey marl and sand with the addition of 3 % to 6 % of rice husk on the thermophysical characteristics: coefficient of thermal conductivity, specific heat capacity and thermal diffusivity. The thermal indicators are measured with a device based on the non-stationary method. The purpose of the research is to investigate the impact of a new type of a light natural organic additive material, the husk of rice grains, on the properties of the resulting composite. The task is to develop a new material which is both thermally efficient and eco-friendly. The results of the research show that the addition of rice husks reduces the coefficient of thermal conductivity by 42 %, of the thermal diffusivity by 38 %, and increases the specific heat capacity by 10 % compared to the reference sample.

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1. Introduction

Over the recent years, more and more efforts have been made to reduce the harmful impact of traditional building materials and to find solutions to construction-induced air pollution responsible for climate changes. Therefore, the needs of construction industry demand harmless and eco-friendly materials to be developed [1–3]. There are many opportunities to construct buildings with environmentally friendly materials and to use renewable energy sources in order to reduce energy consumption in buildings [4, 5]. One of these opportunities for ecologically clean construction is the use of waste biomass from agricultural crops [6, 7]. Globally, large amounts of raw materials are obtained from agricultural waste biomass such as straw, corn stalks, rice husks, etc., which can be used to produce building materials such as bricks, cladding boards, etc. [8–10]. Raw materials from waste biomass are easily available and cheap on the one hand, and on the other hand, they contribute to the reduction of air pollution, thus having a favourable effect on the climate change, which makes them a preferred choice for use in construction [11, 12]. Bricks are the main material in construction because of their compactness and light weight, easy transfer of heat, which is preserved for a long time, etc. The usefulness of brick in construction has been proven over time and has been used since ancient times. Two of the important characteristics of bricks produced from agricultural waste materials in combination with cement, sand and water are the coefficient of thermal conductivity and the specific heat capacity [13, 14]. The lower the value of the coefficient of thermal conductivity, the better the thermal insulation properties of the material. The higher the value of the specific heat capacity, the better the accumulative properties of the material, i.e. the heat is retained for a longer time [15–18]. The search for and implementation of newer building materials in construction requires knowledge of their thermophysical characteristics such as thermal conductivity, specific weight, specific heat capacity, etc [19–22].

According to the investigations carried out so far, there is a significant lack of information on the development of ecological marl bricks with the addition of biomass, in particular rice husks (RH) in different quantities. This motivated conducting research on the thermophysical characteristics of composites made of grey marl, sand, rice husks and water. The publication presents the obtained results for thermal conductivity coefficient k, specific heat capacity Cp and thermal diffusivity a, as well as their analysis.

The aim of the present research is to study the impact of different amounts of rice husks added to a mixture of grey marl and sand on the thermophysical characteristics of the obtained samples. In the literature, there are no similar studies focused on the thermal characteristics of environmentally friendly materials. The growing trend towards sustainable architecture and construction with sustainable materials, including natural materials, the established principles of green and circular economy require continuing and profound search for new materials adapted to modern trends for construction purposes. Therefore, it is vital to point out the real advantages that materials with a slight addition of biomass have with a view to supporting the comfort of buildings. This article investigates eco-friendly materials based on grey marl, sand and rice husk, in response to the growing interest in new environmentally friendly and energy-efficient materials from agricultural crop waste materials.

2. Methods

Experimental studies were carried out on samples of ecological composite materials with different additions of rice husks in order to identify their basic thermophysical characteristics such as: coefficient of thermal conductivity, specific heat capacity and thermal diffusivity.

2.1. Preparation of the samples

For the purposes of the study, four types of samples were made based on grey marl and sand with different addition of rice husks (Table 1 and Fig. 1). The water binding ratio was 0.5. Each mixture was shaped into five cubes with a side of 0.10 m.

Table 1. Composition and density of the samples.

Sample	Weight ratio			Rice husks	Bulk density
№	grey marl	sand	water	wt%	kg/m^3
1	1	2	0.5	0	1920±
2	1	2	0.5	3.0	1840±
3	1	2	0.5	4.0	1760±
4	1	2	0.5	6.0	1625±

Figure 1. General view of the rice husks.

The bulk density of the dry samples was measured on the 14th day of age. Table 1 shows the data on the average volume density of the samples. The addition of rice husks from 3 % to 6 % resulted in a density decrease by about 9 % to about 20 %, respectively, compared to the density of the reference sample without light addition.

2.1.1. Sample preparation methodology

The experimental samples were made by following the following steps. First, the natural grey marl was mixed with water, where it plasticized, and then medium-grained dry quartz sand was added. For the production of samples 2, 3 and 4, the pre-weighed amounts of rice husks were added in weight percentage ratios as indicated in Table 1. All ingredients were mixed with a blender until a homogeneous mixture was obtained. Next was the moulding of cubes with a side size of 0.10 m in wooden moulds (Fig. 2).

Figure 2. Manufacturing stage.

Figure 3. General look of the finished samples.

Laboratory conditions at air temperature of 23±3 °C and humidity 65 % for 5 days. On the sixth day, the samples were removed from the wooden mould (Fig. 3). The samples were smoothed with sandpaper to avoid measurement errors. Until the time of conducting the tests. the samples were stored in laboratory conditions at a temperature of 23±3 °C and humidity of 65 %.

2.2. Methodology of experimental measurement

The measurement of the thermophysical characteristics (thermal conductivity coefficient k, volumetric heat capacity $Cv(C.\rho)$ and thermal diffusivity a of the samples being tested was carried out with an Isomet 2114 device [23]. The device affords a wide range of direct measurements of isotropic materials, such as dense and porous materials, plastics, glass and minerals. The measurement range of the coefficient of thermal conductivity is from 0.015 to 7.0 W/(m.K). and for the volume specific capacity – from 4.0E+04 to 4.0E+06 J/(m^3.K). The measuring device has two types of probes: a needle probe for soft materials and a surface flat probe for hard materials. The measurement data is saved in the internal memory of the device or exported to a computer, as shown in Fig. 4.

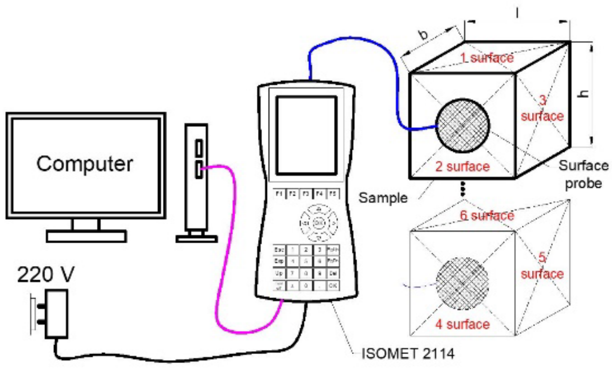

Figure 4. Scheme of the experimental measurement of thermophysical characteristics.

The experimental studies were carried out in compliance with the methodology for using the device. The measurements were carried out under non-stationary conditions. The measurement method was based on an analysis of the measured temperature difference during heating or cooling of the tested sample at heat flow pulses. The heat flow was induced by an electrical heating resistor embedded in the probe, which is in direct thermal contact with the sample being tested.

The measurements for the present study were carried out with a surface probe IPS 1105 on the surface of the sample in the range indicated in Table 2. The surface probe has long-term stability in the measurement range used. Before the measurements, the accuracy of the device was verified by using the cork calibration standard which comes with the device, and the calibration coefficient was given as per the requirements of the ASTM 5334-08 standard [24].

Table 2. Technical characteristics of the measurement [23].

Characteristic	Measurement range	Accuracy in the measuring range
Temperature t, °C	–15…+50	n.a.
Volumetric heat capacity $Cv(C.\rho)$, J/(m³.K)	1.5E+06…3.0E+06	15 % of reading + 1E+03 J/m³.K
Thermal conductivity coefficient k, W/(m.K)	0.30–2.00	in a range 0.015 .. 0.70 W/m.K –5 % of reading + 0.001 W/m.K in a range 0.70 .. 6.0 W/m.K – 10 % of reading

After setting the measuring range, a measurement followed within about 20 min. Throughout the measurement process, the amount of heat generated by the device was known. The heat in the tested samples dissipated radially. The increase in temperature of the tested sample changed linearly with the logarithm of time. In this way, it was possible for the coefficient of thermal conductivity of the tested sample to be obtained directly, and also the data to be transferred to a computer.

The experimental measurements were carried out on the levelled surfaces of the tested samples (Fig. 5 and 6).

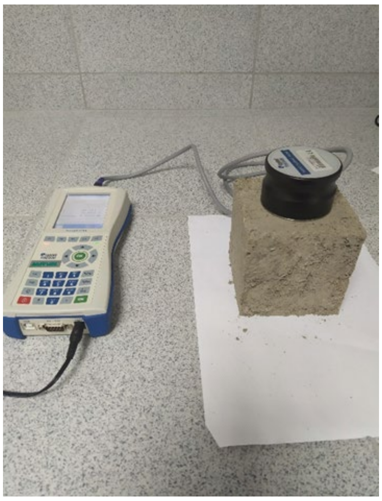

Figure 5. Experimental measurements.

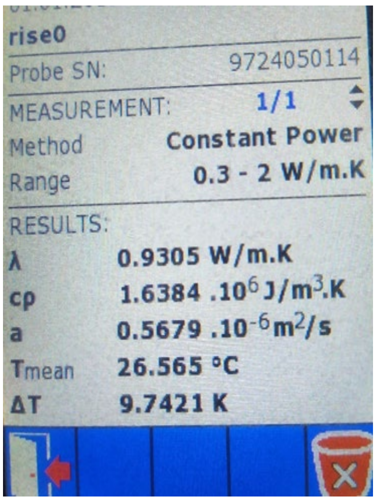

Figure 6. Measurement of sample No. 2.

Equation 1 is used for the samples tested.

$$y = a \times x \pm b. \quad (1)$$

On the basis of the measured thermal parameters, the specific heat capacity Cp was calculated using the formula [25]:

$$Cp = k / (a \times \rho). \quad (2)$$

3. Results and Discussion

As a result of the conducted measurements of the thermophysical characteristics of all samples, values were obtained for the coefficient of thermal conductivity, the volumetric heat capacity and thermal diffusivity. Six series of measurements were carried out for each sample. The values for reference sample No.1 are given in Table 3.

Table 3. Measurement results of the reference sample No. 1

Sample No. 1	k W/(m.K)	a m²/s	Cv J/(m³.K)
Averadge value	1.0698	6.3742E-07	1.6801E+06
Median	1.0687	6.3664E-07	1.6793E+06
Standard deviation	0.0236	1.8007E-08	7.9280E+04
Coefficient of variation, %	2.20	2.82	4.72

Due to the large amount of data from the measurements, after transferring them to a computer from the measuring device, the data were processed statistically to obtain values for average value, median value, standard deviation and coefficient of variation. The results of the measurements for samples No. 2, No. 3 and No. 4 are presented in Tables 4, 5 and 6, respectively.

Table 4. Results for sample No. 2.

Sample No. 2	k W/(m.K)	a m²/s	Cv J/(m³.K)
Averadge value	0.9018	5.4681E-07	1.6502E+06
Median	0.9009	5.4495E-07	1.6556E+06
Standard deviation	0.0168	1.4887E-08	5.4574E+04
Coefficient of variation, %	1.86	2.72	3.31

Table 5. Results for sample No. 3.

Sample No.3	k W/(m.K)	a m²/s	Cv J/(m³.K)
Averadge value	0.7828	4.8614E-07	1.6098E+06
Median	0.7984	4.9685E-07	1.6094E+06
Standard deviation	0.0807	4.9016E-08	5.8319E+03
Coefficient of variation, %	10.32	10.08	0.36

Table 6. Results for sample No. 4.

Sample No. 4	k W/(m.K)	a m²/s	Cv J/(m³.K)
Averadge value	0.6242	3.9776E-07	1.5672E+06
Median	0.6341	4.0697E-07	1.5646E+06
Standard deviation	0.1104	6.6663E-08	1.8376E+04
Coefficient of variation, %	17.68	16.76	1.17

The research results show that the addition of rice husks has a positive effect on the thermo-technical characteristics.

The coefficient of thermal conductivity changes from 1.0698 W/(m.K) for the material without addition of rice husk to 0.6242 W/(m.K) for the material with 6 wt% light additive, which is a reduction of approximately 42 %. The specific structure of rice husks and the inhomogeneous structure of the tested samples exert a significant effect on the coefficient of thermal conductivity, and, in particular, on the repeatability of the data. As can be seen from Tables 3–6, with the increase of the proportion of rice filler, the thermal conductivity of the materials decreases, but along with this, there is also an increase in the standard deviation of the results. This could be explained, on the one hand, by the fact that the measurement is superficial and local (below the surface of the sensor with a diameter of 60 mm) and the results that are reported are for volumes with different structure, different distribution of the additive material and mould share. On the other hand, the shape of the rice particles is not perfectly spheroidal, but rather spindle-shaped and slightly tapering in one direction (Fig. 1). From a structural point of view, this is seen as a prerequisite for anisotropy and inhomogeneity. Moreover, the particles are randomly located in the volume of the tested samples, which leads to the so-called quasi-isotropicity.

The volumetric specific capacity also changes with the change in the amount of added rice husks in the samples, whereby the increase in the proportion of biomass results in decrease of Cv.

The obtained values for the thermal diffusivity range from 6.3742E-07 m^2/s to 3.9776E-07 m^2/s depending on the percentage content of rice husks – from 3 % to 6 %, respectively.

The statistically processed results of the samples tested for coefficient of thermal conductivity, volumetric specific capacity and thermal diffusivity versus on the percentage content of rice husks are shown in Fig. 7, 8 and 9.

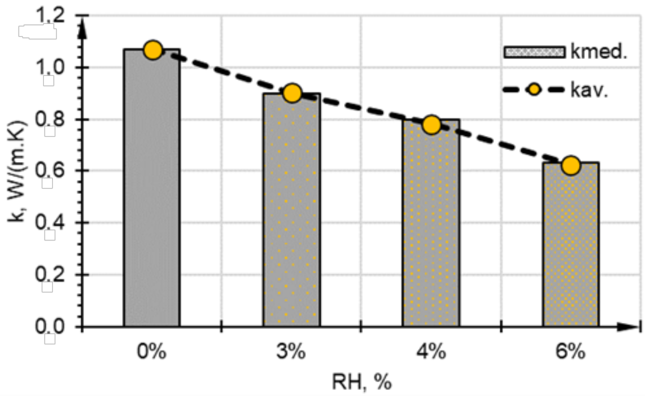

Figure 7. Statistically processed results of the samples tested for coefficient of thermal conductivity versus on the percentage content of rice husks.

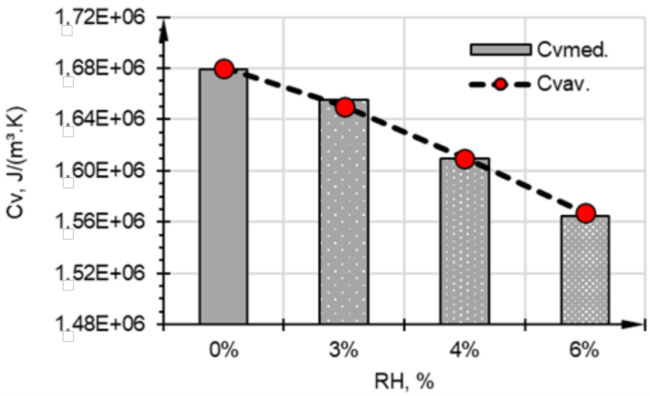

Figure 8. Statistically processed results of the samples tested for volumetric specific capacity versus on the per-centage content of rice husks.

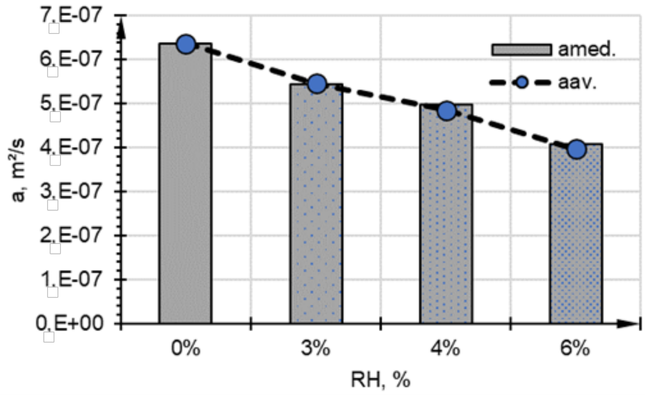

Figure 9. Statistically processed results of the samples tested for thermal diffusivity versus on the percentage content of rice husks.

The graphs in Fig. 7, 8 and 9 clearly show the tendency towards decrease of the studied thermophysical characteristics with the increase of the content of rice husks.

Table 7. Calculated values of the specific heat capacityю

Sample	1	2	3	4
Cp, J/(kg.K)	875.1	896.9	914.7	964.4

The results (Table 7) show that the addition of rice husks improves the specific heat capacity of the tested materials. The analysis shows that the addition of 6 % rice husk increases the specific heat capacity from 875.1 J/(kg.K) for the base material without a light additive to 964.4 J/(kg.K), which is an increase of about 10 %.

Fig. 10, 11 and 12 shows the relationships between the coefficient of thermal conductivity, thermal diffusivity and the specific heat capacity as a function of the density of the samples.

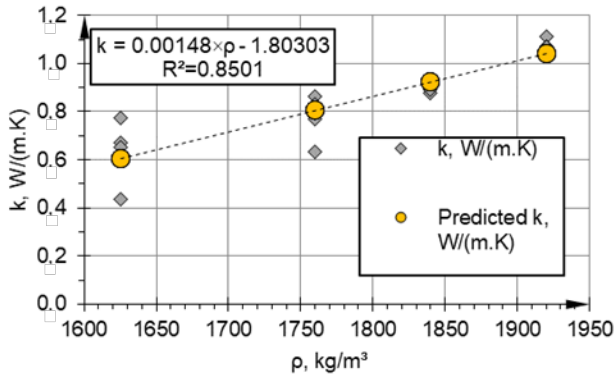

Figure 10. Dependence of the thermal conductivity coefficient as a function of the density – $k = f(\rho)$.

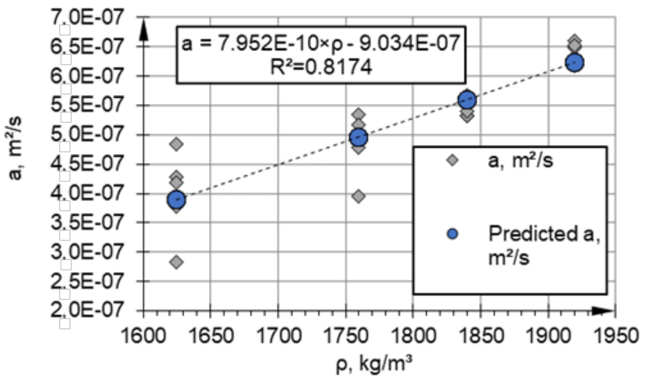

Figure 11. Dependence of the thermal diffusivity as a function of the density – $a = f(\rho)$.

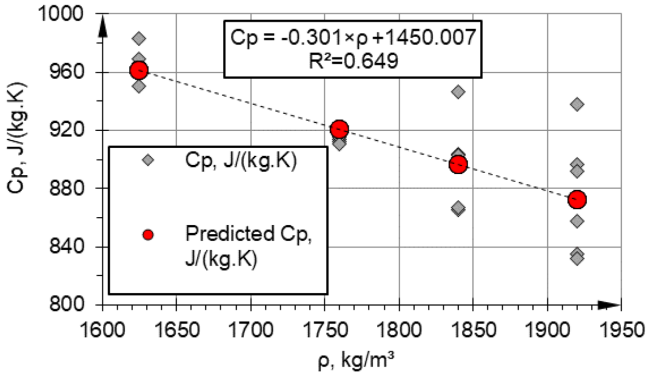

Figure 12. Dependence of the specific heat capacity as a function of the density – $Cp = f(\rho)$.

The increase in rice husk additives can be useful in the development of thermally efficient lightweight eco-friendly building materials.

Fig. 10 and Fig. 11 show the same direction of the two parameters of the tested samples, and Fig. 12 shows the opposite direction compared to the previous two figures. As the coefficient of thermal conductivity decreases, a decrease in thermal diffusion and an increase in specific heat capacity are observed. The relationship between these parameters can be indirectly attributed to the density of the studied samples.

For the tested samples, dependencies equations from 3 to 5 were proposed.

$$k = 0.00148 \times \rho - 1.80303,\ \mathrm{W/(m.K)}; \tag{3}$$

$$a = 7.952.E - 10 \times \rho - 9.034.E - 07,\ \mathrm{m^2/s}; \tag{4}$$

$$Cp = -0.301 \times \rho + 1450.007,\ \mathrm{J/(kg.K)}. \tag{5}$$

The additions of rice husks, as used in the samples, lead to higher air content, specific porosity and a respective decrease in thermal conductivity and heat transfer.

The authors of paper [20], present hand-mixed clay with different percentages of sawdust (0 %, 4 %, 6 %) to evaluate its effect on the thermal performance of unfired bricks. The obtained composites were characterized by densities of 2133 kg/m^3, 1883 kg/m^3 and 1876 kg/m^3. The corresponding values of thermal conductivity were 0.8954 W/(m.K), 0.7996 W/(m.K) and 0.7395 W/(m.K). Experimental results show that the addition of both rice husk and sawdust positively affects the quality of building materials and other heat transfer properties.

In article [26], the authors also used clay with different percentage additions of rice husks. The researchers obtained that bulk density of clay bricks was decreasing with increasing rice husk content. The results indicated that the values of bulk density of the samples containing rice husk (0 %–10 %) varied from 1890 to 1370 kg/m^3.

4. Conclusion

1. This research work presents the results of experiments carried out with samples based on grey marl, sand and different ratios of rice husks: 0 %, 3 %, 4 % and 6 %. We studied the basic thermophysical characteristics of the materials such as: coefficient of thermal conductivity k, thermal diffusivity a and specific heat capacity Cp. The addition of rice husks as a light additive results in reduction of density by 15 % and an improvement of thermal insulation properties of the material.
2. It was found that with a content of rice husks of 6 wt%, all the studied thermal characteristics change significantly. The coefficient of thermal conductivity decreases by 42 % and the thermal diffusivity decreases by 38 %, while the specific heat capacity increases from 875.1 J/(kg.K) to 964.4 J/(kg.K), resulting in an improvement of about 10 % compared to the reference case.
3. The research shows that the combination of grey marl and sand with addition of rice husks gives good results, which can potentially be used in the development of low-cost eco-friendly and energy-efficient materials.

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